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Soil Vapor Extraction VOC Control Technology Assessment

Pacific Environmental Services, Inc., Durham, NC

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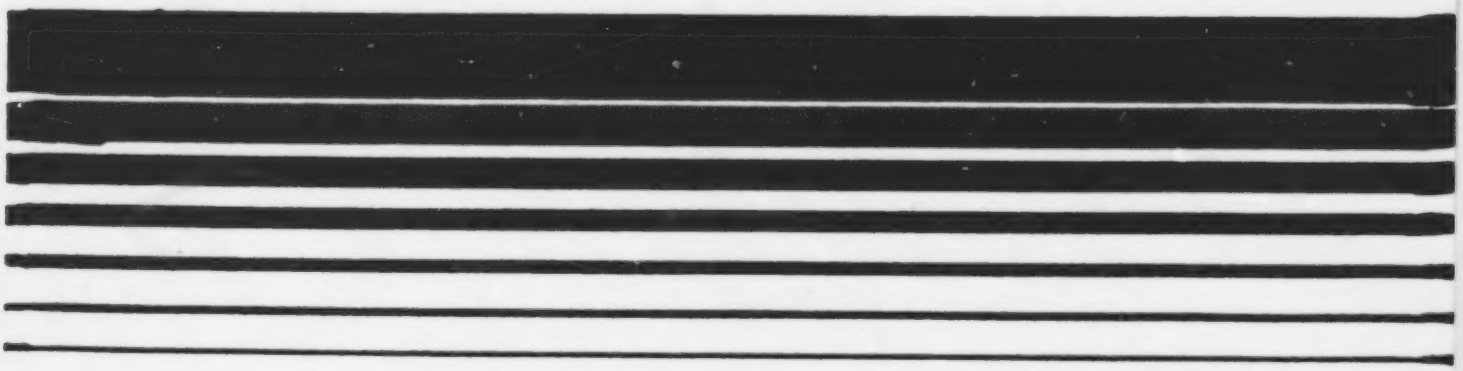

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SOIL VAPOR EXTRACTION VOC CONTROL TECHNOLOGY ASSESSMENT

By

Pacific Environmental Services, Inc.
Durham, NC 27707

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Office Of Air Quality Planning And Standards
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TABLE OF CONTENTS

SECTION	Page
1.0 INTRODUCTION	1-1
2.0 BACKGROUND	2-1
2.1 Soil Contamination and Alternative Remediation Techniques	2-1
2.1.1 Bioremediation	2-1
2.1.2 Incineration	2-2
2.1.3 Solvent Washing	2-3
2.1.4 Extraction/ Flush-wash	2-3
2.1.5 Volatilization	2-3
2.1.6 Encapsulation	2-3
2.1.7 Capping	2-3
2.1.8 In-Situ Stream Air Stripping	2-4
2.2 Data Gathering Approach	2-4
2.3 Soil Vapor Extraction Installations	2-4
2.4 Soil Vapor Extraction Discussion	2-8
2.4.1 Background Information	2-8
2.4.2 SVE operation	2-8
2.5 List of References	2-11
3.0 TECHNOLOGY OPTIONS FOR VOC TREATMENT	3-1
3.1 Emission Controls	3-1
3.1.1 Carbon Adsorption	3-1
3.1.2 Thermal Incineration	3-4
3.1.3 Catalytic Incineration	3-5
3.1.4 Condensers	3-5
3.2 List of References	3-6

TABLE OF CONTENTS (continued)

SECTION		Page
4.0	SELECTED STUDIES FOR SVE/VOC TREATMENT SITES	4-1
4.1	Site Discussions	4-1
4.1.1	Twin Cities Army Ammunition Plant	4-1
4.1.2	Custom Products	4-6
4.1.3	Seymour Recycling	4-6
4.1.4	Verona Well Field	4-7
4.1.5	Hill Air Force Base	4-7
4.1.6	Groveland Wells	4-7
4.1.7	Waldick Aerospace	4-8
4.1.8	Commencement Bay/S. Tacoma Channel	4-8
4.1.9	Wayland	4-8
4.1.10	Dowell Schlumberger	4-9
4.1.11	LARCO	4-9
4.2	List of References	4-10
5.0	VOC CONTROL EQUIPMENT COST ESTIMATES	5-1
5.1	Carbon Adsorption Cost Estimates	5-1
5.1.1	Carbon Canister Systems	5-1
5.1.2	Fixed Bed Regeneration Systems	5-4
5.2	Catalytic Incinerator Cost Estimates	5-10
5.2.1	Catalytic Incinerator Equipment Costs	5-10
5.2.2	Total Capital Investment for Catalytic Incinerators	5-10
5.2.3	Annualized Costs for Catalytic Incinerators	5-10
5.3	List of References	5-15
6.0	HEALTH EFFECTS INFORMATION CONCERNING SVE EMISSIONS	6-1
6.1	Worker Protection Values	6-1
6.2	Chronic Toxicity Values	6-1
6.3	Carcinogenic Risk Concentrations	6-2
6.4	Lowest State Air Toxic Concentrations	6-2
6.5	Chemical Health Effects	5-2
6.6	List of References	6-11
APPENDIX A		A-1

LIST OF FIGURES

Figures		Page
2.1	Typical SVE System with VOC Treatment	2-9
5.1	Equipment Costs of Catalytic Incinerator Systems	5-11

LIST OF TABLES

Table		Page
2.1	Listing of Identified Soil Vapor Extraction Sites	2-5
3.1	Air Emission Requirements for SVE Installations in Selected States	3-2
3.2	Key Emission Stream Characteristics for Selecting VOC Treatment Systems at SVE Sites	3-3
4.1	Selected SVE Sites Utilizing VOC Treatment Systems	4-2
4.2	Emission Stream Parameters from Selected SVE Installations	4-4
5.1	Equipment Costs for Canister Units	5-3
5.2	Unit Cost Factors for Carbon Adsorption Annualized Costs	5-5
5.3	Equations for Carbon Adsorption Annualized Cost Estimate	5-6
5.4	Installation Factors for Fixed Bed Carbon Adsorbers	5-9
5.5	Installation Factors for Catalytic Incinerator Systems	5-12
5.6	Unit Cost Factors for Catalytic Incineration Annualized Cost	5-13
6.1	Worker Protection Values	6-4
6.2	EPA Reference Dose Values for Chronic Toxicity	6-5
6.3	10^{-6} Carcinogenic Risk Concentrations	6-6
6.4	Lowest State Air Toxic Values	6-7

CHAPTER 1

INTRODUCTION

Soil Vapor Extraction (SVE) is an emerging technology in which volatile organic chemicals (VOC) are extracted from soil through use of a vacuum system. Fresh air may be injected or drawn into the subsurface at locations in and around contaminated soil to enhance the extraction process. The VOC laden air is withdrawn under vacuum from recovery or extraction wells which are placed in selected locations within the contaminated site. This air is then either vented directly to the atmosphere, or it is vented to a VOC treatment system such as a carbon adsorber or a catalytic incinerator prior to being released to the atmosphere. The decision to employ a VOC control system treatment is largely dependent upon VOC concentrations and applicable regulations. The selection of a particular VOC treatment option may be somewhat more complicated and based upon individual site characteristics.

Pacific Environmental Services, Inc. (PES) was contracted by the U.S. EPA to investigate and evaluate potential VOC control techniques for use at SVE sites. The purpose of the investigation is to gain insight into the operation of SVE systems in general and to develop and summarize information on the factors associated with determining applicable VOC control systems. These factors include the feasibility, relative cost, and performance of various air pollution control techniques.

Chapter 2 of this report consists of a brief overview of SVE design and operation. It also includes a listing of SVE facilities identified during this investigation. Chapter 3 presents a discussion of the feasible VOC control systems and general guidelines in selecting a control technique. Chapter 4 identifies specific sites utilizing VOC control systems and also includes a brief discussion on specific site criteria. If possible, the principle contaminants at each site are also given. The information contained in Chapter 4 is based upon a literature review as well as upon responses to site questionnaires. Chapter 5 presents capital and annualized cost estimation techniques for selected VOC control treatment systems. Chapter 6 provides a summary of potential health effects of the contaminates extracted at each site and relates exposure health effects values of these contaminates to ambient concentrations with potential for health effects. The reader must then determine if specific site values warrant further investigation.

CHAPTER 2

BACKGROUND

Soil Vapor Extraction (SVE) is one of several potential soil remediation techniques available. However, unless VOC emissions are controlled, this process results in contaminants simply being transferred from one medium (soils) to another (the atmosphere). This may be advantageous in some cases where the pollutant half-life is significantly shorter in the atmosphere than in soils. For the most part though, the release of VOC compounds to the atmosphere may be as damaging to the environment as their presence in soils.

This study is designed to examine potential add-on VOC control techniques available for SVE sites. Specifically the focus is on the general applicability, performance specifications, reliability, and capital and operating costs of these techniques. SVE system operation and design is also briefly discussed.

2.1 SOIL CONTAMINATION AND ALTERNATIVE REMEDIATION TECHNIQUES

Typically, soil contamination is the result of one or more of four main sources. An obvious common source would be leaking underground storage tanks. Other sources include inadequate disposal and storage practices, accidental spills and landfill leachate.

These sources may result in contamination from an extremely wide variety of compounds including metals and various toxics as well as VOCs. Moreover, the pollutant concentrations will vary appreciably from site to site with no uniform or typical concentration evident. This investigation focuses upon the use of SVE with subsequent VOC treatment as the remediation technique for soil contamination. SVE is employed as a remediation technique for VOCs in soils and is less useful for other contaminants such as heavy metals, which are not volatile. This technique is discussed in detail in Section 2.4. Some other remediation techniques are briefly discussed below. They are mentioned here merely to acquaint the reader with some alternative techniques currently available.

2.1.1 Bioremediation

Bioremediation is a technique which enhances the biochemical mechanisms naturally present in soils to degrade organic and inorganic compounds. Microorganisms are introduced into contaminated soils via an injection system. The efficiency of this technique is dependent upon soil moisture and requires careful process control to establish the appropriate microbial population. The technique has proved successful

in treating pesticides and halogenated alphatic compounds located within about three feet of the surface.

Advantages of this process include no transportation costs (since no soil is removed), and low operation and maintenance costs. Disadvantages include incomplete destruction of some compounds and treatment times that may last several years.

2.1.2 Incineration

This technique is actually comprised of several different thermal degradation methods, including conventional pyrolysis, rotary kiln, fluidized bed, and multiple hearth incinerators. Each method is discussed in more detail below.

2.1.2.1 Conventional Pyrolysis

This technique is best suited for sludges, solids, or liquid wastes containing a large amount of volatile hydrocarbons. The waste is fed into an indirect-fired chamber, where it is heated to between 1,000 and 1,600°F. Typically, either just enough oxygen is injected to generate the required heat, or the hot gases are recycled back to the pyrolyzer. This process results in high destruction efficiencies of volatile organics present, but requires a large capital investment, highly trained personnel, and a potentially hazardous char.

2.1.2.2 Rotary Kiln

This incinerator consists of a refractory lined steel cylinder, positioned at a slight incline, and rotated. Rotary kilns are usually equipped with secondary combustion chambers to ensure complete combustion of off-gases. Residence times will average up to four hours for some solid wastes, and temperatures usually average 1,200°F. The rotary action provides air turbulence, solids mixing, and enhances heat transfer to the solid waste. These systems offer good reliability, and high organic destruction efficiencies. Disadvantages include high capital and operating costs, the need for skilled operators, and frequent replacement of the refractory lining if abrasive or corrosive wastes are incinerated.

2.1.2.3 Fluidized Bed

A fluidized bed incinerator consists of a refractory lined steel reactor vessel which contains a bed of inert material such as silica sand. This material is heated to the desired temperature and then fluidized by air blowing up through the bed. These incinerators offer high organic destruction efficiencies, but require high capital and operating costs, limitations on suitable waste forms, highly trained personnel, and emissions of particulate matter that will require controls.

2.1.2.4 Multiple-Hearth

These incinerators consist of a steel shell containing several vertically stacked hearths. Waste solids and sludges are introduced

into the top hearth and eventually fall through drop holes to the bottom hearth. Air is introduced into the bottom hearth and flows up counter current to solids flow. Multiple hearth incinerators work best with wastes having fairly uniform size characteristics, to avoid plugging the drop holes. This technique is well suited for incinerating sewage treatment plant sludges. It is less well suited for controlling organics, as most of these compound volatilize in the top hearth. After-burners can be used to control organics but destruction efficiencies are usually not as high as with other incineration techniques.

2.1.3 Solvent Washing

This technique consists of excavating soils from contaminated areas and washing the contaminants from the soil using water or an aqueous solution. The contaminated effluent is then treated or disposed. For this technique to be effective, it is important to ensure that the contaminates are soluble either in water or in a selected aqueous solution.

2.1.4 Extraction/Flush-Wash

Extraction/flush-wash involves the washing of contaminants from soils using water or another aqueous solution which is injected into the contaminated area. This mixture is then pumped to the surface for removal, recirculation, or onsite treatment and reinjection. This technique is generally limited to compounds that are water soluble, since substitution of another aqueous solution typically includes organic compounds which are pollutants themselves.

2.1.5 Volatilization

In this treatment system, contaminated soils are removed from the area and the solvent constituents are allowed to volatilize into the atmosphere. However, this simply results in a transfer of contaminants from one medium to another, without any control of the pollutants. Moreover, control of VOCs emanating from soil volatilization is difficult since the VOCs are fugitive emissions.

2.1.6 Encapsulation

This technique consists of excavating contaminated soils and preparation of a non-permeable membrane into which the contaminated soils are placed. Typical membranes include synthetic and/or compacted clay liners. In essence, this technique is landfilling and therefore must comply with numerous RCRA requirements.

2.1.7 Capping

Capping is similar to encapsulation except that the contaminated soils are not removed from the site. Instead, a non-permeable membrane is simply placed over the area to prevent the escape of volatile contaminants into the atmosphere. This technique, while certainly suitable at many sites, involves no real cleanup of the contaminated

soil. Capping is typically used in conjunction with SVE to enhance VOC migration to the extraction wells.

2.1.8 In-Situ Steam Air Stripping

This technique, still in development stages, uses steam and hot air injection wells to remove petroleum and chlorinated hydrocarbons from contaminated soils. The system consists of two hollow blades that inject steam and hot air into the soil at a depth up to thirty feet. The mixture heats the soil and raises the temperature of the chemicals, enhancing their evaporation rate. Eventually the chemicals migrate to the surface where they are trapped in a metal box and piped to a processor. The processor condenses the chemicals into liquid, which is eventually sent to an incinerator.

2.2 DATA GATHERING APPROACH

The approach used to obtain information involved contacting EPA Regional and State representatives, and SVE equipment vendors. In general, equipment vendors were very reluctant to reveal information concerning locations of SVE systems, let alone design details. It was therefore decided to concentrate on extracting information through EPA and State contacts. Initially, both Superfund and RCRA administrators within EPA Regional offices were contacted. It was hoped that at least some Regions would be able to use computerized data bases to search for all SVE sites within that Region. However, it was found that presently, such a database is not available to any Region, though efforts to incorporate all SVE sites onto a computer database are underway in some Regions. Instead, Regional personnel provided information on SVE sites known to be active and appropriate State contacts for these sites.

Other sources employed during this phase of the investigation include a literature search and an examination of the Record of Decision (RODs) database. This is a computerized listing of potential and selected remediation techniques for various landfill sites throughout the country. It is not limited to SVE, and in fact SVE sites are a relatively small part of the total database. Nonetheless, several sites were identified through this method.

2.3 SOIL VAPOR EXTRACTION INSTALLATIONS

This investigation identified 29 soil vapor extraction systems within the United States. Information on these installations is presented in Table 2.1. The actual number of sites in the country is certainly higher than this figure, but the actual number includes numerous smaller sites that are only in operation for a period of days or weeks, and may be controlled by private industry. Given these facts. information on these sites is difficult to accumulate, and it was decided to concentrate upon the larger sites where more extensive engineering work had been performed.

Table 2.1

LISTING OF IDENTIFIED SOIL VAPOR EXTRACTION SITES

Facility/Location	State	Region	Pollutants Identified	VOC Control Equipment	Reference
Groveland Wells, Groveland	MA	1	TCE, PCE, MC, DCE, TCA	Y	1
Service Station, Wayland	MA	1	Gasoline	Y	1,2
Waldick Aerospace	NJ	2	PCE, Petroleum Hydrocarbons	Y	3
Industrial Tank Farm	P.R.	2	Carbon Tetrachloride		4,5
Service Station, San Juan	P.R.	2	Gasoline		5
Tyson Dumpsite, Tyson's Lagoon	PA	3	TCE, Toluene, Ethylbenzene, Xylene, Trichloro-propane, 1,1,1,2-TTCA	Y	4,6
Service Station, Bellview	FL	4	Gasoline	N	4
Aware Study, Nashville	TN	4	TCE, Acetone Chlorobenzene	N	4
Petroleum Fuels Terminal, Grainger	IN	5	Gasoline	N	4,5
Seymour Facility, Seymour	IN	5	1,2-DCA, Benzene, Vinyl Chloride, 1,1,1-TCA, Others	Y	8

Table 2.1 -- continued

LISTING OF IDENTIFIED SOIL VAPOR EXTRACTION SITES

Facility/Location	State	Region	Pollutants Identified	VOC Control Equipment	Reference
Thomas Solvents Co., Battle Creek (Verona Well Field)	MI	5	DCA, TCA, DCE, TCE, PCE, Vinyl-chloride, Chloroform, Carbon Tetra-chloride, Benzene, Toluene, Xylene, Ethyl-benzene, MEK, MIK	Y	4,7
Kimross Facility, Kimross	MI	5	1,1,1-Trichlo-roethane	N	5
Lansing Facility, Lansing	MI	5	TCE	N	5
Bangor Facility, Bangor	MI	5	Toluene, Benzene, Xylene, Ethylbenzene, Styrene, Ketones, Chloroethane, MC	N	5
Hillside Facility, Hillsdale	MI	5	TCE	N	5
Custom Products, Stevensville, MI	MI	5	PCE	Y	4
Twin Cities Army Plant, New Brighton	MN	5	TCE, TCA, Toluene	Y	9,10
Troy Facility, Troy	OH	5	Acetone, MC TCE, Toluene, Xylene	N	5
Paint Storage Warehouse, Dayton	OH	5	Acetone, Toluene, Xylene, Ketones	Y	4

Table 2.1 -- continued

LISTING OF IDENTIFIED SOIL VAPOR EXTRACTION SITES

Facility/Location	State	Region	Pollutants Identified	VOC Control Equipment	Reference
Texas Research Inst., Austin	TX	6	Gasoline	N	5
Waverly Facility, Waverly	NE	7	Carbon Tetrachloride	N	11
Hill AFB, Salt Lake City	UT	8	Jet Fuel	Y	12
Dowell Schlumberger, Casper	WY	8	Chlorinated Hydrocarbons, Toluene, Xylene, Benzene, Ethyl-benzene	Y	13
LARCO, Casper	WY	8	Toluene	Y	13
Southern Pacific Spill, Benson	AZ	8	Dichloropropene	N	4
Electronics Co, Santa Clara	CA	9	1,1,1-TCA	N	4
Storage Tank, Cupertino	CA	9	TCA, TCE, DCA DCE,	N	4
Well 12A, Tacoma	WA	10	TCE, PCE, MC TTCA, DCA, TCA	Y	4,14
Ponders Corner	WA	10	1,2 DCA, TCE, TTCA	Y	15

Pollutant Key

DCE: Dichloroethene
TCE: Trichloroethene
PCE: Perchloroethene
MC: Methylene Chloride
DCA: Dichloroethane
TCA: Trichloroethane
TTCA: Tetrachloroethane
MEK: Methyl Ethyl Ketone
MIK: Methyl Isobutyl Ketone

2.4 SOIL VAPOR EXTRACTION DISCUSSION

Typically, an SVE system (Figure 2.1) consists of extraction wells, inlet wells (optional), piping headers, vacuum pumps, flow meters, vacuum gauges, sampling ports, an air/water separator (optional), a VOC control system (optional), and a cap (optional). Extraction wells are usually designed to fully penetrate the contaminated soil. These wells are normally constructed of slotted, plastic pipe placed in permeable packing to allow vapor flow into the pipe. The VOC in the contaminated area migrate through the soil into the pipe where it is either released to the atmosphere or vented to an air pollution control device. The decision to employ an air pollution control device is usually dependent upon the expected VOC concentration and applicable regulations. The VOC compounds migrating to the extraction wells will typically be the lighter and middle fraction compounds with molecular weights up to about 200 g/mol or organic compounds containing up to twelve to fifteen carbon atoms. Heavier compounds have more of a tendency to remain in the soil unless the vacuum is increased.

2.4.1 Background Information

A soil vapor extraction system centers upon the extraction of VOC laden air from contaminated soil. Inlet or injection wells, usually located at the boundaries of the contaminated area, may be used to enhance VOC laden airflow to the extraction wells. Inlet wells are passive, with ambient air being drawn into the ground at the well locations due to pressure differentials caused by the removal of air from the extraction wells. Injection wells are active, and force air into the ground at the well locations. Injection wells may be used as part of a closed loop SVE system. The injection well inlet air may supplied by the VOC control treatment exhaust, or the vacuum pump (blower) exhaust at the site engineers discretion.

The piping used in SVE systems is generally PVC (or another plastic) with the headers being either plastic or steel. Some systems employ quick release flanges to allow for movement of inlet and/or extraction wells easily. Some SVE installations contain multiple systems, with each system having its own wells and blowers. Insulation is occasionally used on the piping and headers especially in colder climates to prevent condensate freezing.

In some cases, it may be necessary to install an air/water separator prior to vapor treatment, particularly if carbon adsorption is used. Depending upon the concentration and type of pollutants present, the condensate may then need to be handled as a hazardous waste.

2.4.2 SVE Operation

The operation of an SVE system is relatively simple. The blower (vacuum pump) and other necessary equipment is turned on and the flows come to equilibrium. The steady state flowrate reached for a given system is usually a function of the equipment, flow control devices, system geometry, soil permeability, and site characteristics.

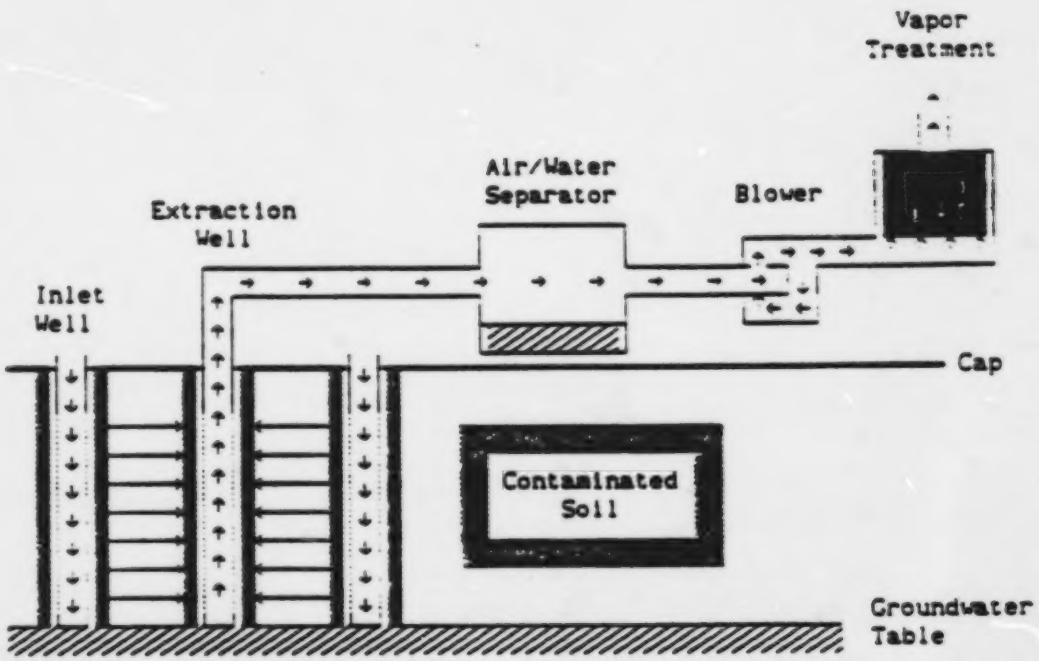

Figure 2.1 Typical SVE System With VOC Treatment

The blower provides reduced pressure in the extraction wells and induces airflow into any inlet wells present. If injection wells are employed, the discharge pressure from the vacuum pump (or after the VOC treatment device if present) is used to inject air into the wells. The reduced pressure in the extraction wells (combined with net airflow from inlet or injection wells if present) is sufficient to volatilize a large number of organic compounds and induce VOC migration to the extraction wells. At the extraction wells, compounds pass through the permeable membrane within the pipe and into the well itself where the VOCs are drawn out of the soil, and towards the vacuum pump.

In some cases, an air/water separator is employed prior to the vacuum pump, to prolong the system life and increase the efficiency of any VOC treatment system present. In addition, a non permeable cap is often placed over the contaminated area to prevent fugitive VOC migration out of the soil, and promote movement towards the extraction wells.

The exhaust air from the vacuum pump is sampled on a routine basis and used in conjunction with flowrate measurements to determine the VOC extraction rate and total amount of VOC extracted from the site. Typically, the extraction rate is initially high and gradually decreases over time. In the latter stages of an extraction operation, the blower is often cycled to conserve energy. This is typically done as follows: the blower is turned on, flows come to equilibrium and the extraction rate is measured. After a period of time has elapsed, the extraction rate is again measured. If the rate has decreased appreciably, the blower is turned off and the site is allowed to settle. After settling, the process is repeated. This procedure is employed because in the latter stages of operation (i.e., after the initial extraction rate has decreased appreciably), the VOC extraction rate becomes diffusion limited by soil moisture, and is not a function of the vacuum applied to the extraction well. In this case, increasing the vacuum to the extraction well will not increase the VOC extraction rate. This is why the site is allowed to "settle." That is, VOCs are allowed to diffuse out of the moisture or particles within the site and into the soil spaces, where they can be subsequently extracted when the blower is turned on.

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CHAPTER 3

TECHNOLOGY OPTIONS FOR VOC TREATMENT

The decision to employ VOC control equipment in conjunction with SVE systems is largely dictated by applicable State regulations. These regulations vary considerably from State to State. A number of States have active and stringent air pollution programs, necessitating the use of VOC control equipment on SVE emissions. Other States appear less active, allowing some SVE emissions to vent directly to the atmosphere. Moreover, the VOC regulations themselves vary from State to State, with some States concentrating on risk assessment, others on maximum allowable emission rates, and still others emphasizing the control of specific compounds. Table 3.1 summarizes emission regulations for several States requiring VOC control of SVE emissions.

3.1 EMISSION CONTROLS

In general, there are four available choices for the VOC treatment system. These include: carbon adsorbers, thermal incinerators, catalytic incinerators, and condensers. Table 3.2 provides general guidelines for selecting vapor treatment systems at SVE sites. These guidelines were developed from conversations with EPA Regional personnel, State and local agency contacts, and published information on air pollution control techniques. A brief discussion of each technique is also presented.

3.1.1 Carbon Adsorption

Carbon adsorption is commonly employed as a pollution control technique and/or for solvent recovery. It can be applied to very dilute mixtures of VOC but typically performs better with concentrations exceeding 700 ppmv. Carbon adsorption units can be designed to achieve efficiencies of 99 percent. Actual efficiencies may be somewhat lower, ranging from 60 to 90 percent, depending upon inlet concentration and other factors such as stream temperature, moisture content (relative humidity), and maintenance. The technique is somewhat sensitive to certain inlet parameters, including both temperature and moisture. Usually, dehumidification is necessary if high humidity (i.e, relative humidity >50 percent) is present. Cooling of the stream is usually required if the stream temperature exceeds 150°F.

An advantage to this technique is that carbon adsorption can usually handle variable stream conditions, such as VOC concentration and flowrate, somewhat better than the other three VOC treatment techniques. This insensitivity lends itself well to the conditions likely to occur at SVE sites where flowrates and concentrations may vary significantly

TABLE 3.1

AIR EMISSION REQUIREMENTS FOR SVE INSTALLATIONS
IN SELECTED STATES

State	Requirement
WA	BACT requirement for new sources including SVE installations. Control equipment decided on case-by-case considering pollutant emitted[1]
WY	BACT requirement for new sources including SVE installations. Control equipment decided on case-by-case considering pollutant emitted[2]
MN	SVE installations fall under odor control and toxics regulations. Decided on case-by-case basis[3]
NJ	Employment of VOC control device decided on basis of maximum allowable emissions (lbs/hr) based upon chemical classification[4]
MA	Emission controls decided on case-by-case considering specific pollutants emitted[5]
PA	Decided on case-by-case basis based upon pollutant rates and air emission standards[6]

1. Reference 1
2. Reference 2
3. Reference 3
4. Reference 4
5. Reference 5
6. Reference 6

TABLE 3.2

KEY EMISSION STREAM CHARACTERISTICS FOR
SELECTING VOC TREATMENT SYSTEMS AT SVE SITES

Vapor Treatment System	Emission Stream Characteristics[b]				VOC Characteristics[b]
	Concentration[a]	Flowrate Moisture	Temp Variation		
Carbon Absorption	>700 ppmv	<50%	Insensitive	<150°F	Molecular weight of VOC should range from 50-150 g/mol for best performance.
Thermal Incineration	>100 ppmv	--	Sensitive	--	Can control most VOCs without operational difficulty.
Catalytic Incineration	>100 ppmv	--	Sensitive	--	Phosphorous, bismuth, lead, mercury, arsenic iron oxide, tin, zinc and halogenated compounds may foul catalyst.
Condensation	>5,000 ppmv	--	Sensitive	<200°F	Removal efficiency limited by vapor pressure-temperature characteristics of VOCs present.

[a] For optimum efficiency. These techniques will control emissions at lower concentrations than those given, although usually at reduced efficiencies.

[b] Reference 7.

over the course of the cleanup. Moreover, this technique performs best with compounds having a molecular weight between 50 and 150 g/mol, or organic compounds containing between about four to ten carbon atoms, which falls into the range of compounds likely to be extracted by SVE systems. Carbon adsorption systems are the most prevalent vapor treatment method at SVE sites. It is typically chosen as the VOC control technique unless the emission stream contains a very high concentration of organics, which would then make catalytic incineration potentially cheaper.

Two different methods to employ carbon adsorption are used at SVE sites. One method utilizes a fixed bed regenerative system allowing reuse of the carbon bed, while the other employs carbon canisters which cannot be reused. The fixed bed systems usually have higher capital and annualized costs relative to carbon canisters. The fixed bed system is typically used at sites where the duration of the cleanup is fairly long. This makes the added cost of the regenerative system economically feasible as compared to replacing canisters. For sites with a relatively short cleanup time, the canister system will likely have reduced annualized costs relative to a regenerative system.

An additional consideration when selecting between the two options is the availability of steam for use as a regenerator. Some locations may not have a ready supply of steam available, which may tend to increase the operating costs and hence annualized costs of a fixed bed system. In these cases, vacuum desorption may be used to desorb the bed.

3.1.2 Thermal Incineration

This technique is widely used to control a variety of emission streams containing VOC. Thermal incineration is able to handle a broader range of compounds compared to other techniques, with efficiencies exceeding 99 percent for concentrations above 200 ppmv. Additionally, this technique can achieve efficiencies exceeding 95 percent for concentrations as low as 50 ppmv, as compared to carbon adsorption which works best with concentrations greater than about 700 ppmv as stated above. Although thermal incinerators can accommodate minor fluctuations in flowrate (e.g., $\pm$ 10 percent), this technique is not well suited for streams with variable flowrate conditions since this tends to change mixing and residence times from design values and hence lowers combustion efficiency.

Thermal incineration can be applied to streams with dilute mixtures of VOC in air and performs best with relatively constant flowrates. Typically, supplemental fuel is required to maintain combustion, especially if treating dilute VOC streams as is the case with numerous SVE sites. This tends to increase operating costs relative to other VOC treatment systems and make this technique less attractive. In fact, thermal incineration is rarely used for VOC treatment at SVE sites, due to relatively high annualized costs. Thermal incineration may be considered at sites requiring little or no supplemental fuel.

3.1.3 Catalytic Incineration

Catalytic incinerators are similar to thermal incinerators in design and operation except that they employ a catalyst to enhance combustion. The catalyst allows the reaction to take place at lower temperatures reducing the amount of supplemental fuel necessary relative to thermal incineration. Typical design efficiencies for this technique are usually around 95 percent although 99 percent is quoted in some cases. Actual efficiencies may be somewhat lower (e.g. 90 percent) depending upon operational and maintenance practices.

This technique is not as broadly applicable as thermal incineration because the catalyst is more sensitive to pollutant characteristics and process conditions. Moreover, compounds such as halogens (e.g. chlorinated hydrocarbons) lead, mercury, tin, zinc, and phosphorous, may damage the catalyst and severely affect performance. Some newer base metal catalysts are better able to withstand moderate concentrations of these contaminants, although these pollutants can still damage the newer catalysts at higher concentrations. Note that the metal compounds are not very volatile and are unlikely to be extracted by SVE in large amounts. Nonetheless, it is possible that a small amount of these metals may appear in the SVE vacuum pump emission stream, and may damage a catalyst if present. Moreover, numerous halogens are light enough to be extracted in large amounts if present in the contaminated soil. This is one reason catalytic incinerators are not usually selected as the VOC control system when heavy metals or halogens are contaminates. Like thermal incineration, catalytic incineration can achieve high destruction efficiencies at low concentrations but is sensitive to fluctuations in inlet stream flowrates. Catalytic incineration, while not as common as carbon adsorption, is employed at selected sites. This technique is usually chosen over thermal incineration for SVE sites because of lower operating costs.

3.1.4 Condensers

Condensers are generally used as raw material and/or preliminary air pollution control devices for removing VOC contaminants prior to other control devices. Condensers are also used as the primary control device for emission streams with concentrations in excess of 5,000 ppmv. This limits their applicability at SVE sites relative to the other three devices.

The nature of VOC concentration in the extraction wells at SVE sites is that of high initial concentration and a lowering of the concentration as VOCs are removed from the soil. This variability in VOC concentration will decrease the overall control efficiencies of condensers at SVE sites. Removal efficiencies for condensers are typically less than that for the other three techniques ranging from about 50 to 80 percent using chilled water. Removal efficiencies approaching 90 percent are possible using subzero refrigerants (e.g., ethylene glycol, freon). This significantly increases capital and operating costs, however. No SVE sites using condensers as the VOC treatment system were found, due to low collection efficiency and high annual costs.

3.2 LIST OF REFERENCES

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CHAPTER 4

SELECTED STUDIES OF SVE/VOC TREATMENT SITES

The purpose of this section is to illustrate how the information presented in Chapter 3 has been utilized in determining remedies for specific sites. Table 4.1 provides a list of selected SVE sites, vapor treatment systems, and pollutants extracted. This information was obtained through conversations and questionnaires with EPA Regional personnel, appropriate State and local agency personnel, and a review of the literature available on specific sites. A brief description of each site given in Table 4.1 is provided below.

The quantity of the data obtained for the various sites presented Tables 4.1 and 4.2 vary appreciably. In some instances, all data gathered was secured through telephone conversations. In other cases, completed questionnaires or site reports were used to obtain the necessary information for SVE installations. Table 4.2 presents the SVE process data for the sites given in Table 4.1. In some cases, a single emission concentration was given, although the VOC concentration will typically decrease over time. Air flow rates given are based upon either design values or actual measured rates.

The presence of VOC control equipment on SVE installations is usually dictated by applicable State regulations. These regulations will vary significantly from State to State as discussed in Chapter 3.

4.1 SITE DISCUSSIONS

4.1.1 Twin Cities Army Ammunition Plant

The plant is located in New Brighton, MN. SVE systems have been used to clean up sites within the plant. The two sites receiving the most attention have been Site D and Site G.

Site D is located on the Arsenal Sand Kame deposit and was likely used for open burning prior to 1970. Soil sampling has revealed soil VOC concentrations up to 8,000 ppm with TCE (trichloroethylene) being the most prominent. Additionally, excessive levels of barium, chromium, lead, phenolics, and PCBs have been found at this site.

Site G is located on the boundary between the Arsenal Sand Kame deposit and the Twin Cities Formation. This site was used as an open

TABLE 4.1

SELECTED SVE SITES UTILIZING VOC TREATMENT SYSTEMS

Site	Location	Vapor Treatment System	Pollutants Identified
TCAAP Pilot 1	New Brighton, MN	Carbon Adsorption	TCE
TCAAP Pilot 2	New Brighton, MN	Carbon Adsorption	TCE; 1,2-DCA
Custom Products	Statesville,MI	Carbon Adsorption	PCE
Seymour Recycling Corp.	Seymour, IN	Carbon Adsorption	Benzene, Vinyl Chloride, others
Verona Well Field	Battle Creek, MI	Carbon Adsorption	DCA; TCA; DCE; TCE; MEK; MIK; others
Hill AFB	Hill AFB, UT	Catalytic Incineration	Jet Fuel
Groveland Wells	Groveland, MA	Carbon Adsorption	TCE; PCE; MC; DCE; TCA
Waldick Aerospace	Well Township, NJ	Carbon Adsorption	PCE, Petroleum Hydrocarbons
Well 12A	Tacoma, WA	Carbon Adsorption (proposed)	TTCA; TCA; TCE; MC; others
Service Station	Wayland, MA	Carbon Adsorption	Gasoline
Dowell Schlumberger	Casper, WY	Catalytic Incineration (Area 1)	Toluene, Benzene, Xylene, Ethylbenzene
Dowell Schlumberger	Casper, WY	Carbon Adsorption (Area 2)	Chlorinated Hydrocarbons
LARCO	Casper, WY	Catalytic Incineration	Toluene

TABLE 4.1 (continued)

SELECTED SVE SITES UTILIZING VOC TREATMENT SYSTEMS

Site	Location	Vapor Treatment System	Pollutants Identified
Paint Warehouse	Dayton, OH	Incineration	Acetone, Toluene; Xylene; ketones 1,2-DCA; 1,1,1-TCA;
Tysons Lagoon	Tysons Lagoon, PA	Carbon Adsorption	TCE; TCP; Toluene; Ethyl Benzene; Xylene; 1,1,1,2-TTCA
Western Processing	Kent, WA	Carbon Adsorber	MC; Chloroform, TCE others
Ponders Corner	Ponders Corner, WA	Carbon Adsorption	1,2-DCA; TCE; TTCA

Pollutant Key:

DCE: Dichloroethene
TCE: Trichloroethene
PCE: Perchloroethene
MC: Methylene Chloride
DCA: Dichloroethane
TCA: Trichloroethane
TTCA: Tetrachloroethane
TCP: Trichloropropane
MEK: Methyl Ethyl Ketone
MIK: Methyl Isobutyl Ketone

TABLE 4.2

EMISSION STREAM PARAMETERS FROM
SELECTED SVE INSTALLATIONS

Site	Flowrate (ff^3/min)	Pollutant Concentration (ppm)	Control Efficiency (%)
TCAAP 1	4,400	500	N/A
TCAAP 2	11,300	200	N/A
Custom Products	N/A	N/A	N/A
Seymour Recycling Corp.	N/A	N/A	N/A
Verona Well Field	1000	N/A	N/A
Hill AFB	1500	2500 (at present) (initial 38,000)	96 average (based on test data)
Groveland Wells	25-155	189 (average)	99 (based on test data)
Waldick Aerospace	250-800	N/A	99 (based on pilot study)
Well 12A	N/A	N/A	N/A
Wayland	600	150 (initial)	N/A
Dowell Schlumberger (Area 1)	90-260	3-260ug/ft^3	≥ 98 (based on test data)
Dowell Schlumberger (Area 2)	50-300	1-15.8 mg/l	≥ 95 (based on test data)

TABLE 4.2 (continued)

EMISSION STREAM PARAMETERS FROM
SELECTED SVE INSTALLATIONS

Site	Flowrate (ft^3/min)	Pollutant Concentration (ppm)	Control Efficiency (%)
LARCO	1500	2500	98 (based on design)
Paint Warehouse	N/A	N/A	N/A
Tysons Lagoon	N/A	N/A	N/A
Western Processing (ST-201)	3450	N/A	90 (based on design)
Ponders Corner	N/A	N/A	N/A

N/A: Not Available

dump between the 1940's and 1970's. Soil testing revealed VOC concentrations in the range of 1,000 ppm with TCE and 1,2-dichloroethylene being the most prominent. Excessive levels of cadmium, chromium, lead, and phenolics were observed at this site.

Both pilot and full scale studies have been performed at the plant. The pilot study was conducted at site D and consisted of injection and extraction wells in addition to a carbon adsorption system. Carbon adsorption was selected over thermal incineration because of operating cost advantages. Catalytic incineration was not selected because of a high probability that compounds present (e.g., halogens, chromium, lead, etc.) may foul the catalyst, as well as somewhat higher operating costs relative to carbon adsorption.

A full scale field system was installed at Site G consisting of injection and extraction wells. A carbon absorber system was selected for vapor treatment for the identical reasons given above at site D. A full scale field system was also installed at site D after completion of the pilot study. The field system at site D did not include any VOC treatment. No reason was given for exclusion of VOC treatment at this site.

4.1.2 Custom Products, Inc.

This facility is located in Stevensville, MI. Cleanup at this site has been completed and the SVE system is currently shut down. The system consisted of six injection wells and one extraction well venting to a carbon adsorber. The primary contaminant was found to be perchloroethylene (PCE). Soil concentrations ranged from 9 to 5,600 ppm within the contaminated area. Carbon adsorption was selected primarily because of low operating costs relative to catalytic and thermal incineration. No further information on the VOC treatment system was provided.

4.1.3 Seymour Recycling

This site is located approximately two miles southeast of Seymour, IN and encompasses a fourteen acre area. From 1970 to early 1980, the Seymour Recycling Corporation (SRC) operated a processing center for waste chemicals. During this period, various wastes stored at the facility leaked and spilled from storage drums creating both odor and fire problems.

A consent decree filed in 1982 resulted in the removal of one foot of topsoil from about 75 percent of the sites surface. Contaminated soil remains however, and extends into aquifers on the site. A SVE system has been chosen to remove the remaining VOCs. The primary pollutants of concern include trichloroethylene, perchloroethylene, benzene, toluene, dichloroethylene, and heavy metals.

At present, the system is still in the planning stage. The system will include a carbon adsorber for treatment of VOCs. This technique was chosen on the basis of low operating cost and the fact that halogens and heavy metals may damage a catalytic incinerator.

4.1.4 Verona Well Field

This site is located outside of Battle Creek, MI and serves as a main potable water source for the city. The Thomas Solvents facility located near the field site was judged responsible for contamination of the wells. The primary contaminants found included perchloroethylene (PCE) and 1,1,1-trichloroethylene. An SVE system was employed at the well field to assist in cleanup and removal of solvents. The system consisted of fourteen extraction wells venting to carbon adsorber canisters, with a backup system to prevent carbon breakthrough. A carbon system was selected over catalytic incineration on the basis of operating costs, and the probability of halogen damage to the catalyst. Carbon canisters were selected over a regenerative system due to an anticipated short cleanup time frame. The exhaust gas is vented to the atmosphere through a 30-foot stack. No information was provided on the criteria for selecting carbon adsorber canisters, nor was any performance or cost information provided.

4.1.5 Hill Air Force Base

This facility is located at the Hill AFB which is about 20 miles north of Salt Lake City, UT. The area was contaminated with over 2,500 gallons of jet fuel in January 1985. The depth of contamination extends to 50 feet in some areas. The SVE system consists of three extraction wells venting to two parallel catalytic incinerators. One incinerator is a fixed bed design, and the other uses a fluidized bed approach. The initial VOC concentration to the inlet of the incinerators was in excess of 35,000 ppmv, which may be sufficiently high to consider condensation, and is presently averaging 2500 ppmv, which is probably not high enough for condensation.

The SVE system provides a vacuum of 50 inches of water at the extraction wells. The flowrate averages between 1200 and 1500 scfm, with a relative humidity exceeding 80 percent. The VOC control system is required by state regulations due to the large volume of contaminates emitted. The selection of the VOC control system was the responsibility of Oak Ridge National Laboratory. The selection criteria was based upon the concentration of contaminates in the extraction wells, and the high relative humidity of the stream. These factors made catalytic incineration a cheaper alternative than carbon adsorption. Test data indicates both incinerators can operate with a destruction efficiency in excess of 99 percent.

4.1.6 Groveland Wells

The site is located at Valley Manufacturing Products Co., Inc. in Groveland, MA. Valley Manufacturing has been operating since the mid 1960's and numerous degreasing solvents and cutting oils have been used at the site. The contamination resulted from a leaking underground storage tank and improper storage and handling of solvents and oils. The SVE system consists of extraction wells and an air/water separator venting to a carbon adsorber canister system. Backup canisters are used to prevent any carbon breakthrough.

Carbon adsorption was selected on the basis of operating costs. Some operational difficulties have been encountered with the VOC treatment system. The canisters were misplaced upstream of the blower intake. This has resulted in excessive water introduction to the activated carbon causing high carbon usage. Proper placement of canisters is usually downstream of the blower to increase the gas stream temperature and decrease the relative humidity into the canisters.

4.1.7 Waldick Aerospace

This site is located in Wall Township, NJ and consists of 12 air inlet wells and three extraction wells. Inlet well placement was situated such that four inlet wells serve each extraction well. Soil sampling revealed perchloroethylene (PCE) to be the primary contaminant, with soil concentrations reaching 1,300 ppm. The SVE system utilizes a variable speed blower which provides flowrates ranging from 200 acfm to 800 acfm.

A carbon adsorber canister system was selected to control PCE emissions from the vacuum pump. A canister type system was chosen over a carbon regenerative system because a canister system is generally cheaper to operate on a short term basis than either a regenerative carbon system or an alternative control technique such as a catalytic incinerator. The canister system is expected to achieve 99 percent control efficiency based upon monitoring conducted during a pilot study.

4.1.8 Commencement Bay/S. Tacoma Channel (Well 12A)

This site is located in Tacoma, WA. Approximately 256,000 ft^3 of soil was contaminated with 1,1,2,2-tetrachloroethane. An SVE system with carbon adsorption for vapor treatment has been selected for the cleanup. The system is presently in the design stage.

A vapor treatment system is considered necessary because the expected VOC concentrations from the vacuum pump will exceed the regulated minimum. A carbon adsorber system has been selected on the basis of cost effectiveness. Additional information on this site may be obtained when the system becomes operational.

4.1.9 Wayland

This is the site of a former gasoline service station that was in operation from the mid 1930's to 1976, when it was closed. However, the underground gasoline storage tanks were not removed until 1985. During removal, it was discovered that the tanks had been leaking, contaminating the soil with gasoline. The SVE system consists of 28 horizontal wells located at a depth between 4 and 4.5 feet. Horizontal wells were employed due to a shallow water table. The system provides a vacuum of about 20 inches of water in the extraction wells. The flowrates average about 50 cfm per well, for a total system flowrate of 1400-1500 cfm.

A regenerative carbon adsorber system was chosen for VOC treatment. Regulations required a VOC treatment system at the site.

However, no rationale for selecting carbon adsorption was given, nor was PES able to obtain performance information on the adsorption system.

4.1.10 Dowell Schlumberger

This site consists of two areas: the "toluene area", and the "abandoned sump area". SVE was chosen as the remediation technique based upon soil porosity, principal soil contaminants, and cost effectiveness.

The toluene area SVE system consists of two extraction wells, a liquid knock-out drum, a particulate dry filter, the vacuum blower, and a catalytic incinerator. The pollutants extracted consist of toluene, benzene, ethylbenzene, and xylenes, with concentrations in the extraction wells varying from about 3,620 ppmv down to 100 ppmv. The initial VOC concentration was high enough to make catalytic incineration feasible relative to carbon adsorption. The flow rate from the extraction wells varies from 50 to 300 cfm. The stream enters the incinerator at about 50°F and exits at 800°F. The choice of catalytic incineration was based upon the states' BACT requirement and the cost effectiveness calculations.

The SVE system for the abandoned sump area consists of two extraction wells, a liquid knockout drum, a particulate dry filter, the vacuum blower, and a carbon adsorption unit. The pollutants extracted consist of a mixture of chlorinated hydrocarbons including tetrachloroethene, trichloroethene, 1,1,1-trichloroethane, 1,1-dichloroethane, and 1,1-dichloroethene. Pollutant concentrations varied from 260 $\mu g/ft^3$ down to about 3 $\mu g/ft^3$. It was not possible to convert this value to a ppmv value because the individual compound concentrations were unknown. A carbon adsorber canister system was selected based upon the BACT requirement and cost effectiveness (the low organic concentration indicates catalytic incineration would require a large amount of supplemental fuel and hence, have a higher cost than carbon adsorption).

4.1.11 LARCO

This site consists of an SVE installation removing petroleum products from the area. The SVE system consists of several extraction wells, a liquid knockout drum, the vacuum blower, and a catalytic incinerator. VOC concentrations venting to the incinerator average around 2500 ppm, with a flowrate of about 1500 cfm. The stream enters at about 50°F and exits at about 600°F. A catalytic incinerator was chosen based upon the States' BACT requirement and cost effectiveness calculations.

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CHAPTER 5

VOC CONTROL EQUIPMENT COST ESTIMATES

This chapter presents a discussion of capital and annualized costs of VOC control equipment employed at SVE installations. Cost data were available in few cases; therefore, for the most part, the cost estimates presented rely solely upon approved EPA costing procedures outlined in Reference 1. These procedures utilize operating and equipment parameters (e.g., flowrates and pollutant concentrations) to provide a study type cost estimate having ± 30 percent accuracy in most cases. In addition, most cost estimates presented in Reference 1 are based on April 1986 dollars. To obtain costs in April 1989 dollars, it is necessary to escalate the Reference 1 costs by three years using the CE equipment index. As a general rule, cost estimates should not be escalated beyond five years. Appendix A contains detailed examples of the costing procedures outlined in this chapter.

5.1 CARBON ADSORPTION COST ESTIMATES

Four types of carbon adsorption equipment is available to collect VOCs: 1) disposable/rechargeable canister system; 2) fixed bed regeneration; 3) traveling bed adsorbers; and 4) fluidized bed adsorbers. Of these, only the first two were found to be employed at SVE installations. Different procedures are used in estimating the costs of regenerative and canister systems. Therefore, they will be discussed separately.

5.1.1 Carbon Canister Systems

Carbon canister systems are normally used for control of lower volume air streams and are generally employed on sources where the expected volume of VOC recovered is fairly small. Carbon canister systems cannot be desorbed at the site, and must be either landfilled, or shipped back to the vendors central facility for desorption. In addition, the effluent from canisters is usually not monitored continuously (via an FID, for example), meaning that operators do not have an indication of breakthrough. Appendix A contains an example of the costing methodology discussed below.

5.1.1.1 Capital Costs for Canister Systems

The capital cost of a canister system is typically a function of only the carbon cost. The carbon cost (Cc, $) is the product of the carbon requirement (Mc, lbs) and the cost of activated carbon ($/lb).

The current cost of activated carbon is about $2/lb (Reference 2). The carbon requirement for canisters can be estimated using equation 5-1 below:

$$Mc = \frac{M_{voc}\ (t)}{A_c} \quad (1 + ND/NA) \qquad 5\text{-}1$$

where: Mc = carbon requirement (lbs)
M_{voc} = VOC inlet loading (lb/hr)
t = adsorption time (hrs)
A_c = adsorption capacity (lbs VOC/lbs carbon)
ND = number of beds desorbing
NA = number of bed adsorbing

The values of M_{voc}, t, and A_c in equation 5-1 may not be known for a given SVE installation. However, note that the product of M_{voc} and t represents an approximation of the amount of pollutant to be extracted, which is usually known. Thus, the amount of pollutant to be extracted (in lb) can simply be substituted as an estimation of the product of M_{voc} and t. The value of A_c was conservatively estimated at 1 lb VOC/10 lb carbon (References 1, 3). Moreover, no beds desorb for cannister systems (i.e. ND = 0). Therefore equation 5-1 can be written:

$$M_c = 10\ [M_{voc}][t] \qquad 5\text{-}1A$$

The number of canisters required is determined by simply dividing the value of Mc calculated from equation 5-1A by the amount of carbon contained within a canister (typically 150 lbs). The result rounded to the next highest digit yields the required canister number, RCN. Equipment costs (EC) for Calgon's Ventsorb canister, common in industry, are provided in Table 5.1. This cost includes the carbon, vessel, and necessary connections, but do not include freight, taxes, or installation charges. The canister costs given in Table 5.1 are estimated based upon the cost of Calgons "BPL" carbon (4 x 10 mesh), a commonly used industrial adsorbent. The costs are given in April 1986 $ and should be escalated using the CE equipment cost index. A factor of 1.08 is used to estimate the costs of taxes and freight.

The cost of materials and labor is significantly less for canister systems than for fixed bed systems. Twenty percent of the sum of the canister costs can be used to estimate the total capital investment (TCI) cost of a canister system as equation 5-2 shows:

$$TCI = 1.2\ [CEC] \qquad 5\text{-}2$$

where: TCI = Total Capital Investment Cost
CEC = Canister Equipment Cost = 1.08 RCN [EC]

5.1.1.2 Annualized Costs for Canister Systems

The annualized cost of a canister system is comprised of direct costs and indirect costs. Direct costs are those which relate to system flowrate and include utilities, raw materials, and operating and

DW:

TABLE 5.1

EQUIPMENT COSTS FOR CANISTER UNITS
(April 1986 $)

Quantity	Equipment Cost EC, each[a]
1-3	$ 687
4-9	$ 659
10-29	$ 622
≥ 30	$ 579

[a] The canister equipment cost CEC, is obtained by multiplying the appropriate equipment cost, EC, by the required canister number, RCN. Costs are quoted for canisters containing 150 lbs of carbon.

maintenance costs. Indirect costs are considered fixed and include overhead, property taxes, insurance, and capital recovery.

For canister systems, utility costs include electricity and solid waste disposal. Other direct costs include operating costs, maintenance costs, and solid waste disposal costs. Indirect costs consist of overhead, property tax, insurance, administrative and capital recovery costs. Tables 5.2 and 5.3 present the necessary factors and equations to estimate direct and indirect annualized cost for canister systems. The information contained in these tables is taken directly from Reference 1, and are presented to give the reader an indication of the estimation method used in this chapter. It is recommended that the reader familiarize himself with the methodology presented in Reference 1 for a more complete understanding of the cost estimation techniques presented herein.

The capital recovery factor is a function of the interest rate and the expected equipment lifespan, in most cases. This factor reflects the fact that most companies incur an opportunity cost when financing the installation of control equipment. Typically, the opportunity cost duration equals the expected equipment lifespan, and the annual interest rate is usually estimated to be 10 percent. For example, carbon adsorbers and catalytic incinerators have typical lifespans of ten years, and are usually installed in plants for control of a continuous process. The process is typically expected to operate at least as long as the control device. At SVE facilities, however, the usual cleanup time is far less than ten years, meaning the VOC control device lifespan for SVE applications will be significantly less than the expected lifespan on a continuous process. It would therefore be inappropriate to estimate the capital recovery factor based upon expected equipment lifespan, since the opportunity cost will not be recovered (or paid out) over a series of years. Since the cleanup duration at SVE sites varies significantly from site to site, but generally lasts much less than one year, the capital recovery factor will be assumed to equal 1.0 as provided in Table 5.2.

Since the control equipment has an expected lifespan of ten years, there may be some salvage value associated with these systems. However, since the salvage value may vary significantly for this equipment, this value is assumed zero in this chapter.

5.1.2 Fixed Bed Regenerative Systems

These units are normally used to control continuous streams over a wide range of flowrates and VOC concentrations. These systems are commonly employed at sites in which the expected cleanup duration is relatively long. Typically, the system consists of two or more carbon beds. One bed will be adsorbing while the other(s) will be either in a regenerative phase or idle.

The capital cost of a fixed bed system is primarily a function of the amount of carbon necessary for control and the cost of the vessels used to enclose the carbon. This in turn, depends upon the amount of pollutant introduced to the system. For SVE installations, this is simply the total amount of pollutants extracted by the SVE systems over

TABLE 5.2

UNIT COST FACTORS FOR CARBON ADSORPTION ANNUALIZED COSTS

Cost Element	Unit Costs Factor
DIRECT ANNUAL COSTS	
1. Utilities:	
a. Steam (C_s)	\$6.00/10^3 lbs 3.5 lbs steam/lb VOC adsorbed
b. Cooling Water[a]	\$0.772 C_s
c. Electricity	\$0.059/kWh
2. Operating:	
a. Operating Labor[b]	\$13.00//0.5 hr/shift
b. Supervisory labor	15% of operator labor
3. Maintenance:	
a. Labor[b]	\$14.30//0.5 hr/shift
b. Materials	100% of Maintenance Labor
4. Replacement:	
a. Carbon[c]	\$2.00/lb
b. Labor	100% of Replacement Carbon
5. Solid Waste Disposal (Canister Systems only):	
a. Disposal Cost	\$72/canister
b. Transportation	As appropriate
INDIRECT ANNUAL COSTS	
1. Overhead	0.60 x (2a + 2b + 3a + 3b)
2. Property Tax, Insurance, and Administrative Costs	0.04 x TCI
3. Capital Recovery[d]	CRF x TCI

[a] Assumes cooling water cost of \$0.225/10^3 gal, taken from Reference 1.
[b] Operating and maintenance labor costs are taken from Reference 4 and have been updated using the CE index.
[c] Reference 2.
[d] CRF is assumed to equal 1.0 as stated in Section 5.2.2.

TABLE 5.3

EQUATIONS FOR CARBON ADSORPTION ANNUALIZED COST ESTIMATE

Cost Item	Equation
1. Direct Costs	
a. Steam Costs, C_s	$C_s = 3.5 \times 10^{-3} M_{voc}$ (HRS) P_s
	where: Mvoc = inlet VOC loading, lbs/hr
	HRS = operating hours per year
	P_s = Steam Price, $/10^3$ lbs
b. Cooling Water Cost C_{cw}	$C_{cw} = 3.43\ C_s\ P_{cw}$
	where: P_{cw} = cooling water price, $/10^3$ gal (assumed to equal $0.225/$10^3$ gal)
c. Electricity	
1. Pressure drop, P_b, for Regenerative Systems (based upon superficial velocity of 60 ft/min.)	$P_b = t_b$ [2.606]
	where: t_b = bed thickness, ft carbon
	or $t_b = \frac{0.0166\ Mc}{LD}$
2. Pressure drop P_c, for canister systems	$P_c = 0.04710_c + 9.29 \times 10^{-4}\ Q_c^2$
	where: Q_c = emission stream flowrate, ft^3/min.
3. System fan horsepower, h_{psf}	$h_{psf} = 2.5 \times 10^{-4}$ [P_b or P_c] Q_c
4. Cooling water horsepower, h_{pcw}	$h_{pcw} = [2.5 \times 10^{-4} q_{cw} Hs]/n$
	where: q_{cw} = cooling water flowrate, gal/min
	H = required head (usually 100 ft H_2O)
	S = specific gravity of fluid
	n = pump and motor efficiency
5. Required electricity usage per year, kWh	kWh = $0.746[h_{psf} + h_{pcw}]$ HRS
D. Carbon Replacement Cost, CRC	$CRC = CRF_c$ [1.08 C_c + Cc_l]
	where: CRF_c = Capital Recovery Factor for Carbon
	C_c = Carbon Cost $/lb
	C_{cl} = Replacement labor cost $/lb (typically about $0.05/lb)

the lifetime of the installation. The auxiliary costs of a fixed bed system such as fans, pumps, condensers, decanters, and piping are usually factored from the costs of carbon and vessels. The costing procedures for regenerative systems contained within this chapter apply to horizontal adsorber vessels only. Appendix A contains an example of the costing methodology discussed below.

5.1.2.1 Costs of Carbon

This cost (Cc, $) is the product of the initial carbon requirement (Mc, lb) and the cost of activated carbon ($/lb). The current cost of activated carbon is about $2/lb (Reference 2). The initial carbon requirement may be estimated in identical fashion to the canister system using equation 5-1, except that a two bed system with one bed desorbing and the other adsorbing (i.e., ND=NA=1) is assumed. Equation 5-1 then becomes:

$$Mc = 160 \ [Mvoc] \qquad 5\text{-}1B$$

The cost of carbon is then:

$$Cc = \$2.00 \ (Mc) \qquad 5\text{-}3$$

where: Cc = carbon costs, 1989$

5.1.2.2 Vessel Costs

This cost (Cv) is primarily determined by vessel dimensions, which in turn, depend upon the amount of carbon contained per vessel (Mc/2), and the superficial gas velocity through the bed, Vb. The value of Vb is typically established empirically. For the purposes of this report, this value is taken to be 60 ft/min. (Reference 1). It is assumed the vessels used are cylindrical. The necessary dimensions can then be calculated using equations 5-4, 5-5, and 5-6:

$$D = \frac{0.127 \ Mc \ Vb}{2 \ Q} = 3.81 \ Mc/Q \qquad 5\text{-}4$$

where Q = volumetric flowrate per adsorbing vessel, (ft^3/min)

$$L = \frac{2 \ (7.87) \ [Q]^2}{Mc \qquad Vb} = \frac{0.00437 \ [Q]^2}{Mc} \qquad 5\text{-}5$$

and $$S = \pi \ D \ (L + D/2) \qquad 5\text{-}6$$

EPA has developed a correlation between S and vessel cost Cv, based upon vendor data and given in equation 5-7:

$$Cv = \exp [18.827 - 3.3945 \ \ln [S] + 0.3090 \ [\ln[S]]^2 \qquad 5\text{-}7$$

where Cv = vessel cost, April 1986 $

and $228 \leq S \leq 2{,}111 \ ft^2$

5.1.2.3 Purchased Equipment Cost

The cost of auxiliary equipment can be estimated as a function of the sum of Cv and Cc as given in equation 5-8.

$$C_A = 1.39 [Cc + Cv (NA+ND)] \quad 5\text{-}8$$

where: C_A = Purchased Equipment Cost of adsorber system

and 1.39 = Factor to account for auxiliary equipment cost

5.1.2.4 Total Capital Investment

The total capital investment (TCI) is estimated from the total purchased cost, C_A, via an overall direct/indirect installation cost factor. Table 5.4 provides the breakdown of the direct and indirect cost factors for fixed bed carbon adsorbers. These cost factors reflect "average" conditions and may vary appreciably from site to site. Also, the cost of site preparation and buildings will depend upon site specific factors and are not included in this analysis.

5.1.2.5 Regenerative Carbon Adsorption Annualized Cost Estimates

The annual operating cost (annualized cost) of regenerative systems is comprised of three elements: 1) direct costs; 2) indirect costs; 3) recovery credits. No data on solvent recovery rates were available for the sites examined. Therefore, the recovery credits for carbon systems examined in this study were assumed negligible. The remaining two annual cost elements are discussed separately. Table 5.2 presents the factors used to estimate direct and indirect annualized costs. Table 5.3 gives the equations used to estimate several components of annual cost. These equations were taken directly from Reference 1, and are presented to give the reader an indication of the estimation method used for these variables. It is recommended that the reader familiarize himself with the methodology presented in Reference 1 for a more complete understanding of the costing methodology presented herein.

Direct Annual Costs. Direct costs are those which are related in some manner to the quantity of gas processed by the control system. This includes costs for utilities (steam, electricity, water, etc.) raw materials, maintenance materials, replacement parts, operating, supervisory, and maintenance labor. Maintenance labor is estimated to be 110 percent of operating labor, to reflect increased skill levels. Carbon replacement costs for regenerative systems are assumed zero for purposes of this report. If necessary, Tables 5.2 and 5.3 can be used to obtain a replacement cost estimate.

Indirect Annual Costs. These costs are usually considered "fixed" costs, in that they are not usually related to the size and operation of control equipment and would have to be paid even if the system shut down. This includes costs for overhead, property taxes, insurance, and capital recovery. Tables 5.2 and 5.3 present the necessary equations to estimate direct and indirect annual costs for regenerative systems.

TABLE 5.4

INSTALLATION FACTORS FOR FIXED BED CARBON ADSORBERS

Cost Item	Cost Factor
DIRECT COSTS	
1) Purchased Equipment Cost	
Adsorber	$C_c + C_v$
Auxiliary Equipment	0.39 $[C_c + C_v]$
Taxes	0.03 C_A
Freight	0.05 C_A
Total Purchased Equipment Cost, TPE	1.08 C_A (C_A = 1.39 $[C_c + [C_v]]$)
2) Installation Direct Costs	
Foundations and supports	0.08 TPE
Erection and handling	0.14 TPE
Electrical	0.04 TPE
Piping, Installation, and Painting	0.04 TPE
Total Installed Direct Cost	0.30 TPE
Total Direct Cost	1.30 TPE
INDIRECT COSTS	
Engineering and Supervision	0.10 TPE
Construction, field expenses, and fee	0.15 TPE
Startup and Performance Test	0.03 TPE
Contingency	0.03 TPE
Total Indirect Costs	0.31 TPE
Total Capital Investment = 1.30 TPE + 0.31 TPE = 1.61 TPE	

5.2 CATALYTIC INCINERATOR COST ESTIMATES

In general, a study type cost estimate of a catalytic incinerator system is somewhat more complex than that of a carbon adsorber. Several process variables have a significant impact on the costs of a catalytic incinerator, including emission stream flowrate, temperature, percent LEL, and heat content. In addition, the preheat temperature, catalyst bed outlet temperature, auxiliary fuel requirements, dilution air requirements, and heat exchanger efficiency are some additional variables necessary to estimate capital and annualized costs. A number of calculations and steps are required to obtain this information, and inclusion of these equations and steps are beyond the scope of this report. A detailed procedure to calculate the necessary variables is presented in Reference 1. For the purposes of this report, it is assumed that these variables are already known.

The reader should note that cost estimates presented in Reference 1 for incinerator systems are unavailable for flowrates under 5,000 scfm. Since many SVE installations operate at lower flowrates, it may be necessary to obtain vendor cost quotes directly for these cases, as extrapolating the cost data in Reference 1 below 5,000 scfm is not recommended. Appendix A contains an example of the costing methodology discussed below.

5.2.1 Catalytic Incinerator Equipment Costs

The equipment cost of a catalytic incinerator can be directly related to the flowrate at standard conditions and heat exchanger efficiency. Figure 5.1 presents the equipment costs of catalytic incinerators (in April 1986 dollars). The equipment includes the burner, fan, housing, skid mounting, instrumentation and controls, a ten foot stack, catalyst, and heat exchanger if applicable. The cost data apply to dilute VOC waste gas requiring a temperature of 600°F at the catalytic bed inlet. The data may be applied to emission streams requiring dilution air by substituting the flue gas flowrate at standard conditions for the emission stream flowrate. The capital cost of a catalytic incinerator system is obtained using a factored approach identical to that described in Section 5.1.1.

5.2.2 Total Capital Investment for Catalytic Incinerators

Table 5.5 provides the factors needed to estimate total capital investment (TCI) of a catalytic incinerator system, from the purchase cost obtained from Figure 5.1. The factors reflect "average" conditions and may vary appreciably from site to site. These factors are taken directly from Reference 1. The cost of site preparation and buildings will depend on site specific factors and are not included in this analysis.

5.2.3 Annualized Costs for Catalytic Incinerators

For incinerators, annualized costs are comprised of two elements: direct costs and indirect costs. No recovery credits are possible with an incinerator system. Table 5.6 presents the factors used to estimate direct and indirect annualized costs. The items comprising direct and indirect costs are discussed below.

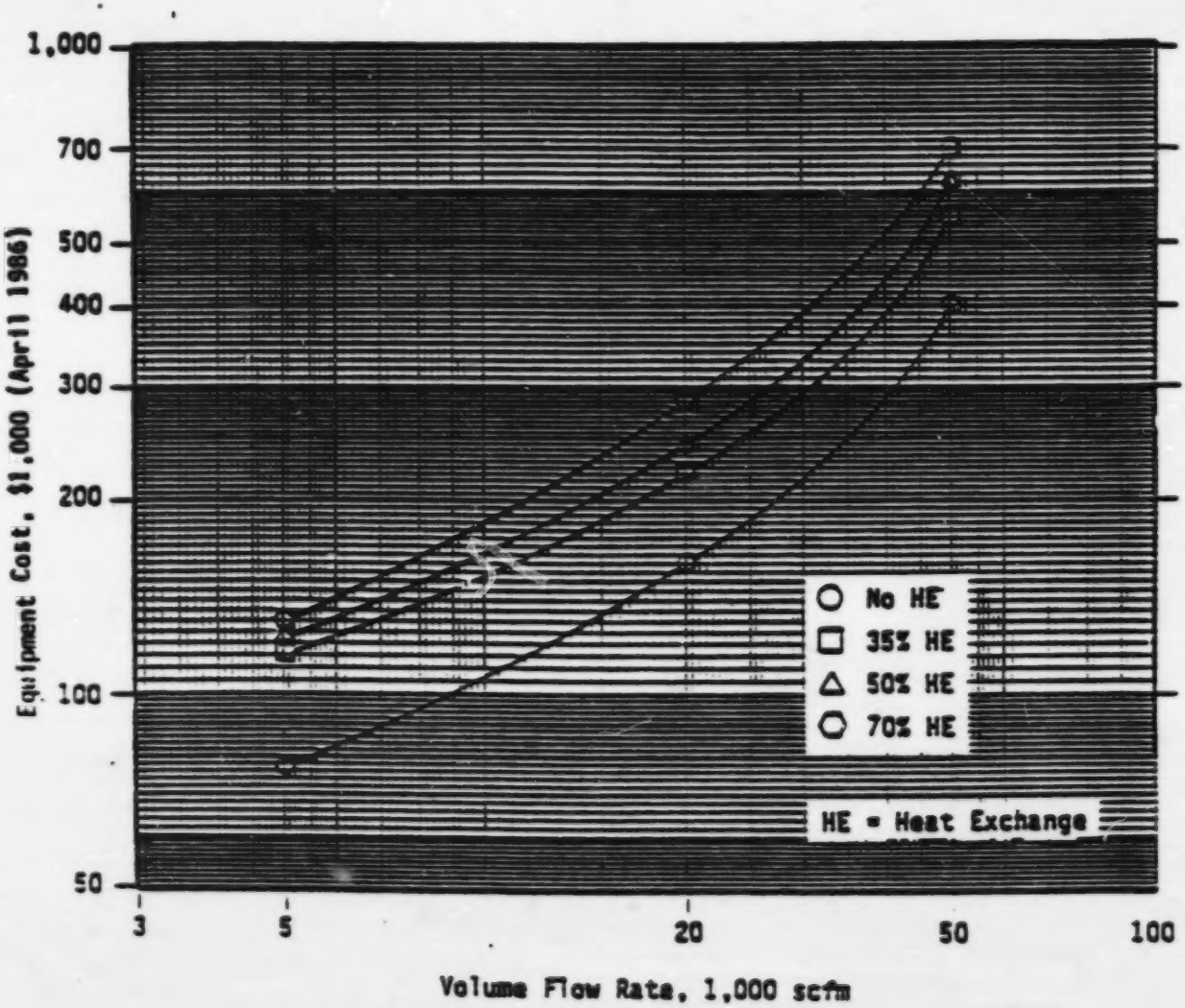

Figure 5.1 EQUIPMENT COSTS OF CATALYTIC INCINERATOR SYSTEMS

TABLE 5.5

INSTALLATION FACTORS FOR CATALYTIC INCINERATOR SYSTEMS

Cost Item	Cost Factor
DIRECT COSTS	
1) Purchased Equipment costs, PEC	
Incinerator	From Figure 5.1
Auxiliary Equipment[a]	As required
Instrumentation and Controls	0.1 PEC
Taxes	0.03 PEC
Freight	0.05 PEC
Total Purchased Equipment Cost, TPE	1.18 PEC
2) Direct Installation Costs	
Foundation and supports	0.08 TPE
Erection and Handling	0.14 TPE
Electrical	0.04 TPE
Piping	0.02 TPE
Insulation	0.01 TPE
Site Preparation (incl. Bldgs)	As required
Total Installation Direct Costs	0.30 TPE & Site Prep.
Total Direct Costs	1.30 TPE & Site Prep.
INDIRECT COSTS	
Engineering and Supervision	0.08 TPE
Construction and Field Expense	0.05 TPE
Construction Fee	0.10 TPE
Start up	0.02 TPE
Performance Test	0.01 TPE
Contingency	0.03 TPE
Total Indirect Costs	0.31 TPE
Total Direct and Indirect Costs or Total Capital Investment, TCE	1.61 TPE & Site Prep.

[a] Includes ductwork and other equipment not normally associated with unit furnished by vendor.

TABLE 5.6

UNIT COST FACTORS FOR CATALYTIC INCINERATION ANNUALIZED COSTS

DIRECT ANNUALIZED COSTS		
1.	Utilities:	
	a. Fuel	See Reference 1 to calculate fuel requirement
	b. Electricity	Use following values of P: Catalytic Incinerator = 6 in. H_2O Heat Exchanger: 35% Efficient = 4 in. H_2O 50% Efficient = 6 in. H_2O 70% Efficient = 15 in. H_2O
2.	Operating Labor:	
	a. Operator Labor[a]	$13.00/hr//0.5 hr/shift
	b. Supervisory Labor	15% of Operator Labor
3.	Maintenance:	
	a. Maintenance Labor	$14.30/hr//0.5 hr./shift
	b. Materials	$100% of Maintenance labor
4.	Replacement Parts	
	a. Catalyst	As appropriate (see Section 5.2.3.1)
INDIRECT ANNUALIZED COSTS		
1.	Overhead	0.60 x (2a + 2b + 3a + 3b)
2.	Property Tax, Insurance, Administration	0.04 TCI
3.	Capital Recovery	CRF[b] [TCI - 1.08 x C_{cat}]

[a] Operating and Maintenance Labor costs are taken from Reference 4 and updated using the CE index.

[b] This factor is assumed to equal 1.0 as discussed in Section 5.2.3.2.

5.2.3.1 Direct Costs

These costs consist of utilities (i.e. fuel and electricity), operating labor, maintenance labor, and replacement parts (i.e. catalyst). Equations to calculate fuel requirements are beyond the scope of this report and can be found in Reference 1. An equation to calculate electricity costs is provided below:

$$C_e = \frac{0.746\ Q\ \ P\ HRS\ Pe\ S}{6356\ n} \qquad 5\text{-}9$$

where: Q = flowrate, acfm
P = pressure drop, in H_2O (see Reference 1 for appropriate value)
HRS = operating hours per year
Pe = Price of electricity
S = Specific gravity of fluid (usually 1.00)
n = combined fan and motor efficiency (usually 60-70 percent)

Assuming that Pe = $0.059/kWh; S = 1.00; and n = 0.65, equation 5-9 becomes:

$$C_e = 1.06 \times 10^{-5}\ Q\ \ P\ HRS \qquad 5\text{-}10$$

Operating labor and maintenance costs are calculated using the factors provided in Table 5.6. Replacement parts include the catalyst. Given that catalyst life is conservatively estimated at two years, it will probably not be necessary to replace the catalyst at SVE installations. If necessary, equation 5-11 can be used to obtain the catalyst replacement costs.

$$CRC = C_{cat} \times 1.08 \times CRF_{cat} \qquad 5\text{-}11$$

where: CRC = Catalyst replacement cost
C_{cat} = Initial catalyst cost ($)
1.08 = factor for taxes and freight
CRF_{cat} = Capital recovery factor for catalyst, equals 0.5762 for catalyst life of two years.

5.2.3.2 Indirect Annualized Costs

As shown in Table 5.6, indirect annualized costs consist of overhead , property tax, insurance and administration, and the capital recovery factor, CRF. For the purposes of this report, the capital recovery factor is assumed to equal 1.0 as discussed in Section 5.1.1.5. For a catalyst incinerator, the purchased cost of replacement catalyst must be subtracted out of the capital recovery factor since it is included in replacement parts, to avoid double counting. Note that if no replacement catalyst is purchased, the capital recovery cost becomes simply the product of the capital recovery factor and the total capital investment. The salvage value of a catalytic incinerator system is assumed to equal zero for purposes of this report.

5.3 LIST OF REFERENCES

1. U.S. EPA. EAB Control Cost Manual (Third Edition). EPA 450/5-87-001A. OAQPS. RTP, NC. February 1987.

2. Telecon. Sink, M. PES, Inc. to Al Roy, Calgon Corp. June 19, 1989.

3. Carbon Adsorption Handbook. P.N. Cheremisinoff and F. Ellerbush, Editors. Ann Arbor Science. Ann Arbor, MI. 1978.

4. U.S. EPA. Handbook. Control Technologies for Hazardous Air Pollutants. EPA-625/6-86-014. September 1986.

CHAPTER 6

HEALTH EFFECTS INFORMATION CONCERNING SVE EMISSIONS

This chapter provides the reader with information which can be used to help evaluate the potential for adverse health effects from SVE emissions. Tables are presented which summarize various types of health concerns for exposure to specific organic compounds identified from SVE installations. By comparing these values with known or estimated levels of ambient concentration, they may be used to begin to assess the potential for adverse health effects from SVE emissions. The values presented reflect the lowest acceptable level of exposure for the noted areas of concern. In addition, a summary of health effects for the specific organic compounds emitted from SVE sites is provided.

6.1 WORKER PROTECTION VALUES

Table 6.1 provides the relevant OSHA permissible exposure limits in 8 hour time weighted average (TWA) concentrations. The permissible exposure limit is defined by OSHA to indicate the maximum concentration of a pollutant to which an employee may be exposed over the duration specified by the limit (e.g. 8 hour TWA). These values are followed by the NIOSH recommended 8 or 10 hour TWA and/or ceiling exposure limits. Finally, the ACGIH exposure limits for concentrations based on an 8 hour work day, 40 hour work week are presented. All values are based on inhalation and expressed as micrograms per cubic meter (µg/m3).

6.2 CHRONIC TOXICITY VALUES

Table 6.2 displays values associated with Dose-Response Assessment for chronic toxicity. These values are expressed as a Reference Dose (RfD) by the Environmental Protection Agency and represent safe daily lifetime exposure limits. All values are based on inhalation and expressed as micrograms per cubic meter (µg/m3).

A Reference Dose represents an estimate of the daily exposure to the human population that is likely to be without a detectable risk of harmful effect during a lifetime (70 years) of continuous (24 hr/day) exposure. The 1989 Health Effects Assessment Summary states that RfDs are used as reference points for gauging the potential effects of other doses. Usually, doses that are less than the RfD are not likely to be associated with health risk.

6.3 CARCINOGENIC RISK CONCENTRATIONS

Table 6.3 presents the quantitative estimates of the 10^{-6} carcinogenic risk concentrations for pollutants identified from SVE installations. The values given in Table 6.3 define concentrations levels (in ug/m^3) that represent significant risk. Significant risk is defined as one cancer case per 1,000,000 (10^6) people exposed over a seventy year lifetime. As an example, a benzene concentration of 0.12 ug/m^3 is estimated to cause one cancer case per 10^6 population exposed continuously over a seventy year lifetime. The values in Table 6.3 are derived from unit risk factors.

6.4 LOWEST STATE AIR TOXIC CONCENTRATIONS

Table 6.4 lists the lowest state air toxic ambient air concentrations for emissions of organic compounds identified as being emitted from Soil Vapor Extractions. The values in this table represent the lowest acceptable chemical concentration a person may be exposed to in some states for either an 8 or 24 hour averaging time period. All values are expressed in units of micrograms per cubic meter ($\mu g/m^3$). For individual State air toxic concentrations see Reference 1.

6.5 CHEMICAL HEALTH EFFECTS

This section addresses the health effects of chemicals involved in the SVE survey. Each chemical is listed with reference to its common or synonymous name followed by information concerning the adverse effects from exposure.

Acetone, commonly referred to as dimethyl ketone, is moderately toxic by various routes. It is a common air contaminant that results in headaches from prolonged inhalation. At 500 ppm it begins irritating the eyes. At this same level it becomes a skin irritant resulting from its defatting action. Acetone is a dangerous disaster hazard. Due to vigorous reactions to oxidizing material, it can cause fire and explosions.

Benzene is a narcotic which is moderately toxic by intraperitoneal and subcutaneous (i.e., beneath the skin) routes. Inhalation and ingestion of benzene effects the blood and central nervous system. Although benzene is moderately toxic through these routes, it may be eliminated chiefly through the lungs, when fresh air is breathed. Benzene causes mild irritation to the skin, but acts as a strong irritant to the eyes. It has been determined poisonous by intravenous exposure and possibly other routes. Chronic benzene poisoning by skin contact has been reported. Benzene has a definite cumulative action, and temporary exposure to relatively high concentrations will likely not cause damage to the blood forming system. However, daily exposure to 100 ppm or less will cause damage over a prolonged period of time. Benzene is a human carcinogen which may be related to myeloid leukemia. It has also been termed an experimental teratogen and tumorigen, and shows mutagenic data.

Carbon tetrachloride, also known as carbon tet and freon 10, is a probable human carcinogen, and experimental teratogen. It is poisonous by ingestion and moderately toxic by inhalation. Central nervous system, pulmonary, gastrointestinal and other systemic effects in humans have been noted. Carbon tet is a narcotic as well as a severe eye and mild skin irritant. Contact dermatitis can result from skin contact. It damages liver, kidneys and lungs. Individual susceptibility varies widely. Dangerous when heated to decomposition, carbon tet emits highly toxic fumes of phosgehe.

Benzene chloride is more commonly referred to as chlorobenzene. It is moderately toxic by ingestion. Chlorobenzene is a strong narcotic with slight irritant qualities. Dichlorobenzols are strongly narcotic. Little is known of the effects of repeated exposures at low concentrations, but damage may be caused to both liver and kidneys.

Ethyl chloride is commonly referred to as chloroethane. It is moderately toxic by ingestion and inhalation. Ethyl chloride is an irritant to skin, eyes, and mucous membranes. It has been noted as harmful to eyes. Ethyl chloride gives warning of its presence, but it is possible to tolerate exposure to it until one becomes unconscious. It is the least toxic of all the chlorinated hydrocarbons. Ethyl chloride can cause narcosis (a stupor), although the effects are usually transient.

Chloroform, also known as trichloromethane, is poisonous to humans by ingestion and inhalation. It is also moderately toxic by intraperitoneal and subcutaneous routes. A suspected human carcinogen, chloroform is termed an experimental teratogen. It is dangerous to life at 14,000 ppm after an exposure for 30 to 60 minutes. The maximum concentration tolerated for several hours or for prolonged exposure with slight symptoms is 2,000 to 2,500 ppm. The harmful effects are narcosis, and damage to the liver and heart. Chloroform causes irritation to the conjunctiva (mucous membranes of the eyes). Experimental data shows that upon inhalation, it causes dilation of the pupils with reduced reaction to light, as well as reduced intraocular pressure. In the initial stages of contact with chloroform, there is a feeling of warmth of the face and body, then irritation of the mucous membrane followed by nervous aberration. Prolonged inhalation will bring paralysis accompanied by cardiac respiratory failure and finally death.

The chemical 1,1-dichloroethylene is synonymous with the names 1,1-dichloroethene, and dichloroethene. Dichloroethene is a poison by inhalation and ingestion. It is also an experimental carcinogen and mutagen by skin contact, inhalation, and other routes. Dichloroethene may also display similar characteristics to vinyl chloride.

Ethylene dichloride is synonymous with the names 1,2-dichloroethane, dichloroethane, and DCA. It is poisonous by inhalation, ingestion, and intravenous routes. Dichloroethane is moderately toxic by skin contact, intraperitoneal, and subcutaneous routes. Vapors produce irritation to respiratory tract and conjunctiva,

TABLE 6.1

WORKER PROTECTION VALUES ($\mu g/m^3$)

CHEMICAL	OSHA	NIOSH	ACGIH
acetone	1,800,000	590,000	1,780,000
benzene	32,446**	320	30,000
carbon tetrachloride	12,600	12,600 (60 min Ceil)*	30,000
chlorobenzene	350,000	---	350,000
chloroethane	2,600,000	---	2,600,000
chloroform	9,780	9,730 (60 min Ceil)*	50,000
1,1-dichloroethene	---	---	20,000
1,2-dichloroethane	4,000	4,050*	40,000
dichloropropene	5,000	---	5,000
ethyl benzene	435,000	---	435,000
gasoline	900,000	---	900,000
jet fuel	---	---	---
ketones	---	---	---
methyl ethyl ketone	590,000	590,000	590,000
methyl isobutyl ketone	205,000	200,000	205,000
methylene chloride	353,577**	lowest feasible limit	350,000
petroleum hydrocarbons	---	---	---
styrene	215,000	213,000*	215,000
1,1,1,2-tetrachloroethane	---	---	---
1,1,2,2-tetrachloroethane	7,000	lowest detectable limit	7,000
toluene	375,000	376,000*	375,000
trichloroethene	270,000	134,000*	270,000
1,1,1-trichloroethane	1,900,000	1,904,000*	1,900,000
1,1.2-trichloroethane	45,000	---	45,000
1,2,3-trichloropropane	60,000	---	60,000
vinyl chloride	2,600**	lowest detectable limit	10,000
xylene (mixed)	435,000	434,000*	435,000

* Conversion based on 25° centigrade

** Conversion based on 20° centigrade

TABLE 6.2

EPA REFERENCE DOSE VALUES

FOR CHRONIC TOXICITY ($\mu g/m^3$)[a]

acetone	ND
benzene	---
carbon tetrachloride	ND
chlorobenzene	20
chloroethane	---
chloroform	ND
1,1-dichloroethene	ND
1,2-dichloroethane	---
dichloropropene	---
ethyl benzene	ND
gasoline	---
jet fuel	---
ketones	---
methyl ethyl ketone	300
methyl isobutyl ketone	80
methylene chloride	3,000
petroleum hydrocarbons	---
styrene	---
1,1,1,2-tetrachloroethane	---
1,1,2,2-tetrachloroethane	---
toluene	5,000
trichloroethene	---
1,1,1-trichloroethane	10,000
1,1,2-trichloroethane	ND
1,2,3-trichloropropane	ND
vinyl chloride	---
xylene (mixed)	1,000

ND- not determined

[a] Reference 2.

TABLE 6.3

10^{-6} CARCINOGENIC RISK CONCENTRATIONS[a] ($\mu g/m^3$)

acetone	---
benzene	0.12
carbon tetrachloride	0.067
chlorobenzene	---
chloroethane	---
chloroform	0.043
1,1-dichloroethene	0.020
1,2-dichloroethane	0.038
dichloropropene	---
ethyl benzene	---
gasoline	---
jet fuel	---
ketones	---
methyl ethyl ketone	---
methyl isobutyl ketone	---
methylene chloride	2.12
petroleum hydrocarbons	---
styrene	---
1,1,1,2-tetrachloroethane	---
1,1,2,2-tetrachloroethane	0.017
toluene	---
trichloroethene	0.59
1,1,1-trichloroethane	---
1,1,2-trichloroethane	0.063
vinyl chloride	0.24
xylene	---

[a] Reference 2, 6, 7.

TABLE 6.4

LOWEST STATE AIR TOXIC VALUES ($\mu g/m^3$)[a]

	AVERAGING TIMES	
	8-HOUR	24-HOUR
acetone	11,800	8,000
benzene	150	1.2
carbon tetrachloride	300	0.67
chlorobenzene	---	---
chloroethane	---	---
chloroform	250	0.43
1,1-dichloroethene	200	0.2
1,2-dichloroethane	20	0.39
dichloropropene	50	80
ethyl benzene	4,350	120
gasoline	18,000	15,000
jet fuel	---	---
ketones	---	---
methyl ethyl ketone	5,900	160
methyl isobutyl ketone	400	54
methylene chloride	1,800	2.4
petroleum hydrocarbons	---	---
styrene	2,150	39
1,1,1,2-tetrachloroethane	6.3 (annually)	---
1,1,2,2-tetrachloroethane	34.4	1.2
toluene	1,870	51
trichloroethene	1,350	6.1
1,1,1-trichloroethane	19,000	1200
1,1,2-trichloroethane	225	0.99
1,2,3-trichloropropane	3,000	14.3
vinyl chloride	50	1.0
xylene (mixed)	2,170	59.2

[a] Reference 1.

corneal clouding, equilibrium disturbances, narcosis, and abdominal cramps. This substance has been listed as a possible human carcinogen by the EPA.

The chemical alpha-chloroallyl chloride is commonly referred to as dichloropropene. It is poisonous by inhalation and ingestion and moderately toxic by dermal route. Dichloropropene is a strong irritant that has shown mutagenic data. This chemical has produced liver and kidney injury in experimental animals.

Ethyl benzene typically causes irritation to skin and mucous membranes. A concentration of 0.1% of the vapor in air is an irritant to human eyes. A concentration of 0.2% is extremely irritating at first, then causes dizziness, irritation of the nose and throat and a sense of constriction in the chest. No data is available regarding the effect of chronic exposure. Ethyl benzene is an experimental teratogen.

Gasoline (from 50-100 octane) is synonymous with the name petrol. Gasoline is a common air contaminant, moderately poisonous by inhalation. Repeated or prolonged dermal exposure causes dermatitis, as well as blistering of the skin. Inhalation and ingestion routes cause central nervous system depression. Pulmonary aspiration can cause severe pneumonitis. Some addiction has been reported from inhalation of fumes. Brief inhalations of high concentrations can cause a fatal pulmonary edema. Overexposure can cause hyperemia of the conjunctiva and other disturbances of the eyes. Sufficient high concentrations in air can cause it to become an asphyxiant.

Kerosene is synonymous with the names jet fuel, kerosine, and coal oil. It is a poison by intravenous route. Kerosene is slightly toxic by ingestion causing irritation of the stomach and intestines with nausea and vomiting. Aspiration of vomitus can cause serious pneumonitis, particularly in young children. Inhalation of high concentrations of vapor can cause headache and stupor.

Ketones are associated with synonyms such as dimethyl ketones and acetone, but no general statement can be made to the toxicity of this compound. Some are highly volatile and may have a narcotic or anesthetic effect. Skin absorption as well as inhalation may be routes of entry into the body. None of the ketones have been shown to have a high degree of chronic toxicity.

The chemical 2-Butanone is commonly referred to as methyl ethyl ketone or MEK. It is an experimental teratogen. MEK is moderately toxic by ingestion and dermal routes. It acts as an strong irritant and affects peripheral nervous system and central nervous system. Eye irritations occur at 350 ppm. MEK may also display similar characteristics to ketones.

Hexone is commonly referred to as methyl isobutyl ketone or MIBK. MIBK is moderately toxic by ingestion and inhalation, also poisonous via intraperitoneal routes. It is a human systemic irritant by inhalation and narcotic in high concentrations. MIBK may also display similar characteristics to ketones.

Methane dichloride, commonly referred to as methylene chloride, is poisonous by ingestion and intravenous routes. It is moderately toxic by inhalation and other routes. Inhalation of methylene chloride, effects the blood and central nervous system. It is moderately irritating to the eyes, but acts as a severe irritant to the skin. It has shown mutagenic data, and is referred to as a strong narcotic but has few other acute toxicity effects. It is listed by EPA as a probable human carcinogen.

Petroleum mixtures of hydrocarbons from C2H6 and up are synonymous with the names base oil, crude oil, and coal oil. Petroleum hydrocarbons are noted as an experimental neoplastigen and carcinogen.

Styrene, a chemical which is poisonous by ingestion and intravenous routes, is also moderately toxic by inhalation and intraperitoneal routes. Styrene is a skin and eye irritant. It has shown mutagenic data, and is termed an probable carcinogen. This chemical is a human systemic irritant and central nervous system effects. It can cause irritation, violent itching of the eyes at 200 ppm, lacrimation, and severe human eye injuries. Its toxic effects are usually transient and result in irritation and possible narcosis.

The chemical 1,1,1,2-tetrachloroethane is commonly abbreviated TTCA. This possible human carcinogen displays moderate skin and severe eye irritant. TTCA is a human systemic irritant by inhalation. When heated to decomposition it emits very toxic fumes of Cl-.

Acetylene tetrachloride is synonymous with the names tetrachloroethane, 1,1,2,2-tetrachloroethane, TTCA, and perchloroethene. Tetrachloroethane is poisonous by inhalation and ingestion and moderately toxic by skin contact. This probable human carcinogen is considered to be the most toxic of common chlorinated hydrocarbons. It is an irritant to the eyes, mucous membrane and upper respiratory tract. It can cause dermatitis, produce atrophy and cirrhosis of the liver. Central nervous system and peripheral nerve system effects can result from exposure. Initial symptoms from vapors are lacrimation, salivation, and irritation of the nose and throat. Continued exposure results in restlessness, dizziness, nausea, vomiting and narcosis. Tetrachloroethane shows mutagenic data. It is considered to be a very severe industrial hazard and its use has been restricted or even forbidden in certain countries.

Toluene, also known as methyl benzene, is common air contaminant with human central nervous system and psychotropic effects. Toluene is poisonous by intraperitoneal route, and moderately toxic by inhalation and subcutaneous routes. This chemical typically causes skin and eye irritation. Inhalation of 200 ppm of toluene for 8 hours may cause impairment of coordination and reaction time. Higher concentrations (up to 800 ppm) not only increase these effects but cause them to be observed in a shorter time period. At 200-500 ppm, headache, nausea, eye irritation, loss of appetite, bad taste, lassitude, impairment of coordination and reaction time are reported, but are not usually accompanied by any laboratory or physical findings of significance. At

higher concentrations the same effects occur along with anemia, and leucopenia, and an enlarged liver may be found in rare cases.

Acetylene trichloride commonly referred to as trichloroethene, trichloroethylene, and TCE. It is an air common contaminant poisonous by intravenous route. This experimental carcinogen is moderately toxic by other routes. Trichloroethene is a severe eye irritant. A form of addiction has been observed in exposed workers.

The chemical 1,1,1-trichloroethane, is synonymous with the names TCE, chloroethene, and methyl chloroform. The health effects associated with this chemical are human psychotropic, gastrointestinal, and central nervous system oriented. It is moderately toxic by ingestion and intraperitoneal routes. TCE is a moderate skin and severe eye irritant. In high concentrations it has been labeled narcotic. TCE has been known to cause a proarrhythmic activity, which sensitizes the heart to epinephrine induced arrhythmias. When this material is massively inhaled as drug abuse, it will cause a cardiac arrest. EPA lists this pollutant as a probable human carcinogen.

The chemical 1,1,2-trichloroethane is also known as Beta-trichloroethane. It is poisonous by intravenous and subcutaneous routes and moderately toxic by ingestion, inhalation, skin contact, and intraperitoneal routes. B-trichloroethane is a moderate skin and severe eye irritant. It has narcotic properties and acts as a local irritant to the eyes, nose and lungs. It may also be injurious to the liver and kidneys. This chemical is an experimental carcinogen with mutagenic data. EPA lists this chemical as a possible human carcinogen.

Allyl trichloride is commonly referred to as 1,2,3-trichloropropane. This chemical is poisonous by ingestion, inhalation, and possibly other routes. It is also moderately toxic by skin contact and displays mutagenic data.

Vinyl chloride also known as chloroethene and chloroethylene, is a human brain carcinogen, experimental neoplastigen and tumorigen by inhalation. It causes skin burns by rapid evaporation and consequent freezing. In high concentration, it acts as an anesthetic. It is a severe irritant by inhalation to skin, eyes, and mucous membranes. Chronic exposure of vinyl chloride has shown liver injury. Circulatory and bone changes in the fingertips have been reported in workers handling unpolymerized materials.

Xylene, commonly referred to as aromatic hydrocarbons or dimethylbenzene, is poisonous by intraperitoneal route. It is moderately toxic by inhalation, ingestion, and subcutaneous routes. Xylene is a severe human eye irritant and may cause some temporary corneal effects, as well as some conjunctival irritation. Irritation can start at 200 ppm. It is also a moderate skin irritant with human irritant (systemic) effects.

6.6 LIST OF REFERENCES

1. National Air Toxics Information Clearinghouse. Draft Report, OAQPS, RTP, NC. July 1989.

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3. American Conference of Governmental Industrial Hygienists, Threshold Limit Values and Biological Exposure Indices for 1987-1988. Second Printing.

4. Sax, N.I., and Lewis, R.J., Hawley's Condensed Chemical Dictionary. Eleventh Edition.

5. Sax, N.I., and Lewis, R.J., Hazardous Chemicals Desk Reference.

6. Integrated Risk Information System.

7. Office of Health and Environmental Assessment.

APPENDIX A

CONTROL EQUIPMENT COST ESTIMATES

APPENDIX A

The purpose of this appendix is to provide case examples utilizing the costing procedures outlined in sections 5.1 and 5.2, which are taken from Reference 1. The case examples presented in this section are hypo-thetical examples selected to illustrate the appropriate costing methodology. All three examples assume replacement costs (i.e. carbon, catalyst) to be zero.

A.1.1 Carbon Canister System

Table A.1 contains process information to be used for the purposes of calculating capital and annualized costs for the canister system example. Note that the flowrate for this example is less than the flowrates for the other two examples. This reflects the fact that canister systems are usually employed in cases where flowrates are fairly low.

A.1.1.1 Capital Cost Estimate

The capital cost estimate for this system follows the methodology given in Section 5.1.1. First, equation 5-1A is used to calculate the carbon requirement, Mc. Using the appropriate value of M_{voc} given in Table A.1, the carbon requirement is 2,000 lbs. This value divided by 150 lbs yields the required canister number (RCN) of 14. From Table 5.1, a canister cost of $622 each (in April 1986 $) is obtained. This cost is escaled to April 1989 $ using a factor of 1.258. This factor was obtained using cost indices of 391.0 (April 1989) divided by 310.9 (April 1986). The escalated canister cost (EC) then becomes $780. This value is multiplied by the RCN (=14) and 1.08 to obtain a canister equipment cost (CEC) of $11,800. The total capital investment (TCI) is estimated as 120 percent of this total, or $14,600.

A.1.1.2 Annual Cost Estimate

As stated in section 5.1.1.2, annual costs consist of direct and indirect costs. Direct costs for a carbon adsorption canister system include electricity and solid waste disposal. The pressure drop through a canister system is a function of flowrate and can be estimated using the appropriate equation presented in Table 5.4. However, note that the equation presented for canister systems is based upon a single 150 lb canister. To correctly use the equation in this case, it is necessary to divide the average flowrate by the RCN, to estimate the pressure drop across a single canister. The total flowrate is 500 scfm. The flowrate through each canister is 1/14 of this or 36 scfm. The equation given in Table 5.3 then yields a pressure drop of 2.9 inches of water. The pressure drop of any additional piping is assumed negligible, giving a total system pressure drop of 2.9 inches water. The system fan

horsepower, hpsf, is calculated using the equation given in Table 5.3, the pressure drop calculated above, and the system flowrate given in Table A.1 (500 scfm). The horsepower is found to equal 0.36 hp. There is no cooling water for canister systems, thus hpcw equals zero.

The required electricity usage is calculated using the appropriate equation given in Table 5.3, the horsepower requirement obtained above, and the operating hours given in Table A.1. The annual electricity usage is found to be 135 kWh/yr. The electricity cost is obtained by multiplying this value by the cost of electricity given in Table 5.2 ($0.059/kWh). This yields an annual electricity cost of about $10.

Operating labor costs are estimated by dividing the operating hours (500) by the hours per shift (8) and multiplying this quotient (62.5) by operator hours per shift given in Table 5.2 to obtain a value of 31.3 hours. This value is multiplied by the estimated labor rate of $13.00/hr to obtain an operating cost of $410/yr. Supervisory labor is estimated as 15 percent of this total, or $60/yr. Maintenance costs are estimated in identical fashion except the labor rate is slightly higher to reflect greater skills. Maintenance labor costs are estimated to be $450/yr. Materials costs are assumed to equal this value, at $450/yr.

Solid waste disposal costs consist of transportation and landfill costs. For this example, transportation costs were assumed to be zero. Landfill costs are given in Reference 1 as between $35 and $65 per canister. To obtain a landfill cost estimate, the higher value ($65/canister) was escalated to April 1989 $ using the CE general index. Note that the equipment cost indices are inappropriate since this cost is not equipment related. Using the appropriate indices (354.6/318.4) to escalate the costs to April 1989 $, the landfill costs per canister are about $72. Multiplying this cost by the RCN (14) yields a landfill cost of $1,000.

Indirect cost items include overhead, property tax, insurance and administration, and the capital recovery cost. The capital recovery factor is assumed to equal 1.0 as stated in Section 5.1.1.2.

Overhead costs are estimated as 60 percent of the sum of operating and maintenance costs as shown in Table 5.2. The overhead cost in this case equals $830/yr. Property tax, insurance, and administration costs are estimated at four percent of the TCI ($13,100) or $520/yr. The capital recovery cost is estimated to equal the TCI,or $14,100. Table A.2 presents a summary of the annualized costs for this example.

A.1.2 Regenerative Carbon Adsorber System

For purposes of calculating capital and annualized costs, the information contained in Table A.3 is assumed to have been obtained prior to attempting capital and annualized cost estimates.

TABLE A.1

Item and Description	Value
M_{voc}, inlet loading	25 lbs/hr
HRS, Operating hours	500 hrs/yr
Flowrate, scfm	500

TABLE A.2

ANNUALIZED COSTS FOR CARBON CANISTER SYSTEM

Cost Element	Value
DIRECT ANNUALIZED COSTS	
1. Utilities	
a. Electricity	$ 10
b. Solid Waste Disposal	$1,000
2. Operating:	
a. Labor	$ 410
b. Supervision	$ 60
3. Maintenance	
a. Labor	$ 450
b. Materials	$ 450
4. Landfill	$1,000
Total Direct costs	$3,380
INDIRECT ANNUALIZED COSTS	
1. Overhead	$ 820
2. Property Tax, Insurance, and Administration	$ 520
3. Capital Recovery Cost	$14,100
Total Indirect costs	$15,440
TOTAL ANNUALIZED COSTS	$18,820

TABLE A.3

REGENERATIVE CARBON ADSORPTION PROCESS INFORMATION

Item and Description	Value
M_{voc}, inlet loading	25 lbs/hr
HRS, operating hours	500 hrs/yr
P_s, steam price	\$6.00/10^3 lbs
P_{cw}, cooling water price	\$0.30/10^3 gal
Q_c, flowrate	5000 acfm
H, required head	100 ft. H_2O
S, specific gravity of fluid	1.00
n, pump and motor efficiency	65 percent
C_c, carbon cost	\$2.00/lb
C_{ce}, replacement labor cost	\$0.05/lb
q_{cw}, cooling water flowrate	20 gpm

A.1.2.1 Capital Costs

Proceeding as Section 5.1.2 suggests, equations 5-1B and 5-3 are used to calculate the cost of carbon. These equations yield a carbon requirement of 4,000 lbs and a cost of $8,000. Next, equations 5-4 through 5-7 are used to obtain the vessel dimensions. Using values given in Table A.3, equation 5-4 yields a diameter of 3.05 feet, while equation 5-5 gives a length of 27.3 feet. Equation 5-6 then gives a value of 276 for S. Using equation 5-7 gives a vessel cost in April 1986 dollars of $13,500. This cost is then updated to $17,000 in Spring1989 $ using the CE cost index. Equation 5-8 is then used to obtain the purchased equipment cost of $58,400. The total purchased equipment cost (TPE) includes taxes and freight and is estimated as 108 percent of the purchased equipment cost. The TPE in this example equals $63,100. The total capital investment (TCI) is estimated as a function of the TPE as shown in Table 5.4. A factored estimation method is used to obtain the TCI. For this example, the TCI equals $101,500.

A.1.1.2 Annualized Costs

As section 5.1.2.5 indicates, annualized costs for a regenerative carbon adsorber system includes direct and indirect costs. Direct costs for a regenerative system consists of steam, electricity, and water costs, as well as operating labor, maintenance costs and replacement parts. For the purposes of this report, replacement parts for a regenerative system is assured to be zero given that SVE installations operate for short periods of time.

To estimate the steam costs Cs, the appropriate equation given in Table 5.3 yields a cost of $260 using the values given in Table A.3. Similarly, the cooling water cost is estimated as $270. To estimate the system pressure drop, it is first necessary to calculate the bed thickness. This is done using the equation given in Table 5.3 under electricity costs. The bed thickness for this example is calculated as 0.80 feet. In turn, this yields a system pressure drop (P_b) of 2.08 inches of water. Next, the system fan horsepower, hpsf, is calculated as 2.6 hp. Similarly, the cooling water horsepower, hpcw, is calculated as 0.77 hp. The required electricity usage is then calculated at 1,260 kwh/wk using the appropriate equation in Table 5.3. The electricity cost is then estimated as $80/yr using a cost factor of $0.059/kwh as given in Table 5.2.

Operating labor is calculated using system operating hours per year from Table A.3 (500) and dividing this value by 8 hrs/shift, multiplying by 0.5 hr per shift as given in Table 5.2, and multiplying this product by $13.00/yr. This yields a operating labor cost of $410/yr. Supervisory labor is estimated at 15 percent of this cost or $60/yr. Maintenance labor is estimated in an identical fashion as operating labor, or $450/yr. This higher cost reflects increased skill levels for maintenance personnel. Materials are estimated at 100 percent of this value, or $450/yr. Replacement costs and solid waste disposal costs are estimated to be zero for this case.

TABLE A.4

ANNUALIZED COSTS FOR REGENERATIVE CARBON ADSORPTION SYSTEM

Cost Element	Value
DIRECT ANNUALIZED COSTS	
1. Utilities:	
a. Steam	$ 260
b. Cooling water	$ 270
c. Electricity	$ 80
2. Operating:	
a. Operating Labor	$ 410
b. Supervisory Labor	$ 60
3. Maintenance:	
a. Maintenance labor	$ 450
b. Materials	$ 450
4. Replacement	
a. Carbon	$ 0
b. Labor	$ 0
Total Direct Costs	$1,980
INDIRECT ANNUALIZED COSTS	
1. Overhead	$ 820
2. Property Tax, Insurance, and Administrative	$4,060
3. Capital Recovery	$101,500
Total Indirect Costs	$106,380
Total Annualized Costs	$108,360

Indirect annualized costs consist of overhead which is estimated as 60 percent of operating and maintenance costs, or $820/yr. Property tax, insurance and administration is estimated as four percent of the total capital investment or $4,060. Finally, the capital recovery cost is estimated as $101,500 as stated in Section 5.1.2.5. The salvage value is assumed zero. Table A.4 provides a summary of the annualized costs for this example.

A.2.1 Catalytic Incinerator System

Table A.5 provides data from which the capital and annualized costs of a catalytic incinerator system are estimated. As stated in Section 5.2, calculation of several variables (e.g., supplemental fuel and dilution air requirements, and initial catalyst requirement) arebeyond the scope of this report. Reference 1 can be used to obtain the values for these parameters and to acquaint the reader with a more detailed cost methodology for catalytic incinerator systems. For purposes of this report, it is assumed that the variables given in Table A.5 are known and do not need to be calculated.

A.2.1.1 Capital Cost

Using Figure 5.1, a catalytic incinerator equipment cost of about $79,000 in April 1986 $ is obtained for a flowrate of 5000 scfm with no heat exchanger. The cost of auxiliary equipment is assumed zero for this example. This cost can be updated to April 1989 $ by use of the CE cost index as follows: $79,000 x (391.9/310.6) = $99,700. Table 5.5 can then be used to obtain a total purchased equipment cost of $117,650 (99,700 x 1.18). The total capital investment (TCI) is then estimated as $189,420.

A.2.1.2 Annualized Cost

As stated in Section 5.2.3, annualized costs consist of direct and indirect costs. For a catalytic incinerator, direct costs are composed of utilities, operating and maintenance costs, and replacement parts (i.e., catalyst). Given that SVE installations typically have a short lifetime, it is assumed that no catalyst replacement is necessary and hence, replacement costs are zero.

From Tables 5.6 and A.5, an approximation of the system pressure drop, P, can be obtained, and equals 6 inches of water for the incinerator, and 1 inch water for ductwork and stack for system total of 7 inches water. Equation 5-10 is then used to obtain the electricity cost of $190/yr. From Table A.5, the fuel requirement is taken to be $4,000/yr. Operating costs are estimated by taking the operating hours per year (500), dividing this by 8 hr/shift, multiplying this quotient by 0.5 hrs/shift, and multiplying the result by $13.00/hr to obtain $410/yr. Supervisory costs are estimated as 15 percent of this value, or $60/yr. Similarly, maintenance costs are estimated at $450/yr, with materials also estimated at $450/yr. As stated above, replacement costs are assumed zero for this example.

Indirect annualized costs consist of overhead, property tax, insurance and administration, and the capital recovery cost. The

TABLE A.5

CATALYTIC INCINERATOR PROCESS INFORMATION

Item and Description	Value
Q, System flowrate, scfm	5,000
Heat exchanger efficiency	none required
Fuel requirements	$4,000/yr
HRS operating hours per year	500
S, specific gravity of fluid	1.00
n, combined fan and motor efficiency	65 percent
C_{cat}, initial catalyst cost using base metals)	$18,000
Ductwork and stack pressure drop	1 inch H_2O

capital recovery factor is assumed to equal 1.0 in this report as discussed in Section 5.2.3.2. Overhead costs are estimated at 60 percent of operating and maintenance costs, for a total of $820/yr. Property tax, insurance and administration is estimated as four percent of the total capital investment, or $7,580/yr. Finally, the capital recovery cost equals the total capital investment or $189,420. The equipment salvage value is assumed zero for this case. Table A.6 provides a summary of the annualized costs for this example.

TABLE A.6

ANNUALIZED COSTS FOR CATALYTIC INCINERATOR SYSTEM

Cost Element	Value
DIRECT ANNUALIZED COSTS	
1. Utilities	
a. Electricity	$ 190
b. Fuel	$4,000
2. Operating:	
a. Labor	$ 410
b. Supervision	$ 60
3. Maintenance	
a. Labor	$ 450
b. Materials	$ 450
4. Replacement	
a. Catalyst	$ 0
Total Direct Costs	$5,560
INDIRECT ANNUALIZED COSTS	
1. Overhead	$ 820
2. Property Tax, Insurance, and Administration	$7,580
3. Capital Recovery Cost	$189,420
Total Indirect Costs	$197,760
Total Annualized Costs	$203,380

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16. ABSTRACT

Soil Vapor Extraction (SVE) is an emerging technology in which volatile organic chemicals (VOC) are extracted from soil through use of a vacuum system. Fresh air may be injected or drawn into the subsurface at locations in and around contaminated soil to enhance the extraction process. The VOC laden air is withdrawn under vacuum from recovery or extraction wells which are placed in selected locations within the contaminated site. This air is then either vented directly to the atmosphere, or it is vented to a VOC treatment system such as a carbon adsorber or a catalytic incinerator prior to being released to the atmosphere. The decision to employ a VOC control system treatment is largely dependent upon VOC concentrations and applicable regulations.

The purpose of the report is to provide insight into the operation of SVE systems in general and to develop and summarize information on the factors associated with determining applicable VOC control systems. These factors include the feasibility, relative cost, and performance of various air pollution control techniques.

The report consists of a brief overview of SVE design and operation and includes a listing of SVE facilities identified during this investigation. The report also identifies specific sites utilizing VOC control systems and includes a brief discussion on specific site criteria. The report presents capital and annualized cost estimation techniques for selected VOC control treatment systems.

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